REMARKS

The present Amendment is in response to the Examiner's Final Office Action mailed October 17, 2006. Claims 19 and 20 are cancelled and claims 21 and 32 are amended. Claims 1-18, 21-42 are now pending in view of the above amendments.

Reconsideration of the application is respectfully requested in view of the above amendments to the claims and the following remarks. For the Examiner's convenience and reference, Applicant's remarks are presented in the order in which the corresponding issues were raised in the Office Action.

Please note that the following remarks are not intended to be an exhaustive enumeration of the distinctions between any cited references and the claimed invention. Rather, the distinctions identified and discussed below are presented solely by way of example to illustrate some of the differences between the claimed invention and the cited references. In addition, Applicants request that the Examiner carefully review any references discussed below to ensure that Applicants understanding and discussion of the references, if any, is consistent with the Examiner's understanding.

I. INFORMATION DISCLOSURE STATEMENT

The Examiner requests that the Applicants "identify the 20 most relevant references and the specific parts of these references that relate to the claimed subject matter (i.e. any reference that describes an optoelectronic element coupled to an optical fiber or other optical medium via two lenses) so that a more thorough review of this material couple be timely performed by the Examiner."

The Examiner cites no authority for such requirement and the Applicant is unaware of a duty to respond to such a request. Therefore the request is unduly vague. If the Examiner is relying on a law, rule, or administrative procedure for such requirement, the Applicant hereby requests that such authority be set forth so that the Applicant can properly respond. Moreover, it is clear that it is the Examiner's duty to review the art for relevancy, not the Applicant's. *See* MPEP 706.

However, the Applicant is unaware of a reference submitted that teaches the claimed invention. The Applicant has not, however, made a search of, or inquiry into, references cited by previous counsel in this case.

II. PRIOR ART REJECTIONS

A. Rejection Under 35 U.S.C. §102(b)

The Examiner rejects claims 21-24 under 35 U.S.C. § 102(b) as being anticipated by *Gaebe* (United States Patent No. 5,684,901). Because *Gaebe* does not teach or suggest each and every element of the rejected claims, Applicants respectfully traverse this rejection in view of the following remarks.

According to the Examiner on page 3 of the Final Office Action, "*Gaebe* discloses an optical coupler comprising...means for inputting light into an optical medium (the air surrounding the aspherical lens, 48, may be considered to be an optical medium, since light passes through air) from the means for aspherically focusing light."

This rejection of claim 21 is improper for several reasons, each of which illustrates the lack of a *prima facie* case of anticipation. First, the Examiner has failed to establish that the aspherical lens is surrounded by air in *Gaebe*. The Examiner does not cite to a portion of *Gaebe* disclosing that the aspherical lens is surrounded by air and the Applicant is unable to identify such disclosure in *Gaebe*. In fact, it is the Applicant's belief that optical components are often packaged in hermetically sealed vacuums. Thus, the Examiner has made an assumption that the embodiments of *Gaebe* are surrounded by air which is not supported by *Gaebe*. As such this allegation by the Examiner goes beyond the scope of what has been disclosed by *Gaebe*. Therefore, the rejection is improper and should be withdrawn. If, however, the Examiner is relying on an inherency argument, such argument is not apparent from the rejection and therefore the rejection is improperly vague and should be withdrawn for this reason as well.

However, as amended, Claim 21 also includes the element, "an optical medium configured to <u>guide</u> the aspherically focused light from said means for aspherically focusing light, the optical medium contacting the means for aspherically focusing light." (Emphasis

added). The Examiner has not shown that the alleged air would guide (as opposed to disperse) light as required by claim 21.

In light of the foregoing, Applicant respectfully submits that the Examiner has failed to establish that *Gaebe* discloses the identical invention in as complete detail as is contained in claim 1. See *MPEP § 2131.*

Claims 22-24 depend from claim 21 and as a result include the same elements as claim 21. Therefore, for at least the reasons set forth above, the Applicant respectfully submits that the Examiner has failed to establish that *Gaebe* anticipates claims 21-24 under 35 U.S.C. § 102(b), and the rejection of those claims should accordingly be withdrawn.

The Examiner rejects claims 1, 21-24, 26-28, 32, and 42 as being anticipated under 35 U.S.C. § 102(b) *Blasingame et al.* (United States Patent Application Publication No. 2004/0247242). Because *Blasingame* does not teach or suggest each and every element of the rejected claims, Applicants respectfully traverse this rejection in view of the following remarks.

On page 12 of the Final Office Action the Examiner sets forth the following:

> Aspheric lenses are lenses that have one aspheric surface. A half-ball lens has a flat surface that is aspheric. For reference only, page 6.34 of the Melles Griot catalog is attached to this Office Action. As can be seen from the description of aspherical condenser lenses on this page, a lens having a spherical side surface and a plano back surface (pictured in the middle at the bottom of the page) is an aspheric lens. A half-ball lens has a spherical side surface and a plano back surface. Furthermore, Figure 3 of the present application illustrates an aspherical lens having a curved surface that forms a portion of a sphere, which appears to be in direct contrast to applicants statement that a spherical lens is a lens whose surfaces form portions of spheres.

The Applicant respectfully disagrees at least for the reason that one of ordinary skill in the art would not construe the half-ball lens 26 in *Blasingame* as an aspherical lens as alleged by the Examiner.

The Examiner does not cite to a source or provide evidence for the Examiner's definition of an "aspheric lens". The Examiner includes a flat surface within the definition of an "aspheric surface". To be consistent with the 'reviewability doctrine' as outlined in *In re Lee*, the Examiner must provide a source for the definition. That source could be a patent, dictionary definition, or other definition found in the prior art. "Tribunals of the PTO are governed by the

Administrative Procedure Act, and their rulings receive the same judicial deference as do tribunals of other administrative agencies." *In re Lee*, 61 USPQ2d 1430, 1432 (Fed. Cir. 2002). If the PTO relies on a definition, the source of the definition must be set forth on the record. *See Id.* The source of such evidence must be made explicit so that the Applicant may respond and the Board may review for sufficiency. *See KSR Int'l Co. v. Teleflex*, No 04-1350, at 14 (U.S. Apr. 30, 2007). A conclusory statement is not sufficient evidence to support a rejection based on obviousness. *Id.* quoting *In re Kahn*, 441 F.3d 977, 988 (Ca Fed. 2006). Thus, until the Examiner sets forth a source for the Examiner's definition of "aspherical lens" the Examiner's rejection is unsupported by evidence, unreviewable, and thus improper.

The Examiner does not understand the meaning of the term "aspherical" as it is understood by one of ordinary skill in the art. In the portion of the Melles Griot catalog cited to by the examiner, it is the aspherically curved surface on the left side of the plano back lens that designates the lens as an aspheric lens, not the plano portion on the right of the plano back lens. In fact, in the concave back and convex back lenses, the Melles Griot catalog clearly differentiates the difference between the aspheric left side of the lenses and the spherical right sides of the lenses.

The plain meaning of the term "aspheric lens", as it is understood by one of ordinary skill in the art does not include a half-ball lens. "[T]he ordinary and customary meaning of a claim term is the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention, i.e., as of the effective filing date of the patent application." *Phillips v. AWH Corp.*, 415 F.3d 1303, 1313 (Fed. Cir. 2005) (emphasis added). The Applicant has previously submitted and explained two excerpts (of many available[1]) including page 216 of *Elements of Modern Optical Design*[2] (attached as Appendix A) and pages 2 and 3 of *Lens Design Fundamentals*[3] (attached as Appendix B). Any introductory lens design or optics design text, such as those excerpts appended hereto, will make clear that neither the spherical surface, nor the

[1] *E.g. see also Fundamental Optical Design*, Michael J. Kidger, pages 57-60 and 159-162 (2002) (attached as Appendix C) the entire contents of which are hereby incorporated by reference; *Lens Design*, Milton Laikin, pages 7-10, 195, and 198 (2007) (attached as Appendix D) the entire contents of which are hereby incorporated by reference; *Lens Design Fundamentals*, Rudolf Kingslake, pages 2, 3 36-38, and 113 (1978) (attached as Appendix E) the entire contents of which are hereby incorporated by reference herein; and *Modern Lens Design A Resouce Manual*, Warren J. Smith, pages 14, 40, 41, 51, and 451 (attached as Appendix F) the entire contents of which are hereby incorporated by reference herein.
[2] Donald O'Shea (1985) the contents of which are hereby incorporated by reference herein

plano surface (a sphere of infinite radius) of the half ball lens 26 in *Blaingame* would be considered to be aspheric surfaces by one of ordinary skill in the art. Not even *Merriam-Webster's Collegiate Dictionary*[4] supports the Examiner's definition of "aspherical".

In lens design, surfaces are generally divided into three classes: spheres, conic section, and general aspheric.[5] An aspheric lens has a "lens surface which departs to a greater or lesser degree from a sphere, e.g. one having a parabolic or elliptical section."[6] An aspheric surface can be defined in several ways, the simplest being to express the sag of the surface from a plane.[7] In some instances, it is better to express the asphere as a high order polynomial equation, such as the example of a high order polynomial equation of the example embodiment discussed on pages 8 and 9 of the Applicant's specification. In other methods, there is a need for some reference surface because in practice an asphere is often defined by its departure from some reference sphere. This is expressed as the difference between the sphere and the asphere at different heights above the optic axis.

These texts illustrate many algorithms with high order polynomials for designing an aspherical surface and none of these algorithms are associated with a half ball lens having a spherical curved side and a plano side as suggested by the Examiner. Rather, a half ball lens is expressly included within the definition of a spherical lens, that is "[a] lens whose surfaces form portions of spheres."[8] Thus, a half ball lens cannot reasonably be considered to be an aspherical lens by one of one of ordinary skill in the art as it is an expressly different type of lens – that is a spherical lens.

Attached hereto as Appendix I is an affidavit under 35 U.S.C. § 1.132 from James Guenter. Mr. Guenter is a named inventor of U.S. Patent Application Publication 2004//0247242 to *Blasingame* under which the Examiner's rejection was made. According to Mr. Guenter, "lens 26 in *Blasingame* is clearly not an aspherical lens." Mr. Guenter continues, "[l]ens 26 is

---

[3] Rudolf Kingslake (1978)
[4] *Mirriam-Webster's Collegiate Dictionary*, pages 73 and 1200 (11th Ed. 2003) (attached as Exhibit G).
[5] *Lens Design*, Milton Laikin (4th Ed. 2007)
[6] *The Wordsworth Dictionary of Science and Technology*, page 54 (1995); *See also The Photonics Dictionary* (Laurin Publishing 1994 edition) ("**Aspheric Lens** – A lens element in which at least one face is shaped to a surface of revolution about the lens axis, including conic sections but excluding a sphere.") (emphasis added); *see also McGraw-Hill Dictionary of Scientific and Technical Terms*, page 138 (5th ed. 1994) ("**Aspheric surface** [optics] A lens or mirror surface which is altered slightly from a spherical surface in order to reduce aberrations.") (attached as Appendix H)
[7] *Lens Design Fundamentals*, Rudolf Kingslake (1978)

explicitly a half-ball lens, and any lens whose surface is any fraction of a sphere is a spherical lens. One having taken an introductory course in optics or lens design would not consider a half-ball lens an aspherical lens."

Mr. Guenter describes in detail the distinction between a half ball lens and an aspherical lens citing to the same textual authority already submitted in support:

> The technical distinction between a spherical lens on the one hand, and an aspherical lens on the other hand, is one that is well known and accepted in the field of optics and optical component design and is a view that is well developed in the literature. For example, excerpts from the following technical texts make it quite clear that any surface that is a portion of a sphere, including a plano surface, cannot be an asphere:
>
> a. The first sentences in section A of Lens Design Fundamentals, by Rudolf Kingslake (Academic Press, 1978) (attached hereto as Exhibit A) teaches that a plano surface is a spherical surface with infinite radius, and the second paragraph teaches that an aspheric surface by definition has an axis of symmetry that must be made to coincide with the optical axis of any design, whereas spherical surfaces, for which any radius is equivalent, have no such axis.
>
> b. Also, pages 215-216 of Elements of Modern Optical Design, by Donald O'Shea (John Wiley and Sons, 1985) (attached hereto as Exhibit B) further demonstrates the technical distinction between an aspherical lens and a spherical lens, such as a half-ball lens. In particular, the cited portions teach that asphere is usually defined by its departure from some reference sphere. This is expressed as the difference between the sphere and the asphere at different heights above the optic axis, as shown in Fig. 6.23. Therefore, the curvature of a half ball lens does not depart from some reference sphere and cannot be considered an asphere.

Mr. Guenter also describes the importance of the distinction between the combination of a glass ball-lens and a plastic aspherical lens as disclosed in the Applicant's specification:

> As disclosed on page 6 lines 13-22 of this application (SN 10/612,660) the combination of the glass spherical lens and the plastic aspherical lens has a synergistic effect where an aspherical plastic lens compensates for the ball lens' spherical aberration and the glass ball lens compensates for poor thermal properties of the plastic aspherical lens. This same synergistic effect would <u>not</u> be realized by a ball lens and half-ball lens configuration.

---

[8] *McGraw-Hill Dictionary of Scientific and Technical Terms* (5^{th} ed. 1994).

> The aberration of the ball lens may degrade the efficiency of the coupling system. However, the ball lens' spherical aberration may be compensated by the light ray directing properties of the aspherical plastic lens. Since the ball lens may have significantly more optical power than the plastic lens in the coupling system, the plastic lens' poor thermal properties may be compensated for and minimized. Therefore, an appropriately designed combination of a glass ball lens and plastic molded aspherical lens may provide a thermally stable and highly efficient optical coupling system.

Page 6 lines 13-22 of U.S. Patent Application 10/612,660.

Thus, the Examiner's definition of "aspherical lens" is clearly not reasonable under the plain meaning as it would be understood to one of ordinary skill in the art. However, even if the Examiner's definition were reasonable under the plain meaning of the term, the definition is inconsistent with the context of the Applicant's specification. The words of a claim must be given their plain meaning unless the plain meaning is <u>inconsistent</u> with the specification. *In re Zletz*, 893 F.2d 319, 321 (Fed. Cir. 1989); see also MPEP 2111.01 PLAIN MEANING. The meaning and context of the term "aspherical lens" is described in the Applicant's specification giving specific examples that are inconsistent with a half ball lens or any other type of spherical lens. For example, the Applicant's specification describes an example of an "aspheric lens" designed according to an aspherical high order polynomial as follows:

> A design for aspherical concave lens 26 may be indicated by the following equation and parameter values.
>
> $$z=\{cr^2/[1+(1-(1+k)c^2r^2)^{1/2}]\}+A_6r^6+A_8r^8$$
>
> Surface 1
>
> c=1/R; R=-1.576039 (Unit: mm)
>
> k=-18.455693
>
> A_6 =-24.768767
>
> A_8=--20.028863

See page 8, line 21 - page 9, line 6 of the Applicant's specification. The Applicant respectfully requests that the Examiner establish that this equation is consistent with the Examiner's definition of an "aspherical lens".

Incorrectly, the Examiner alleges on page 12 of the Final Office Action, "Figure 3 of the present application illustrates an aspherical lens having a curved surface that forms a portion of a

sphere, which appears to be in direct contrast to applicants statement that a spherical lens is a lens whose surfaces form portions of spheres." Lens 46 does not have a curved surface that forms a portion of a sphere. Again, it is the curved portion of aspheric lens 46 that is an aspheric surface not the plano surface. The Examiner's mischaracterization of the Applicant's figures makes clear the misunderstanding by the Examiner as to the meaning of an aspheric lens as it is understood to one of ordinary skill in the art. Therefore, construing a spherical half ball lens as an aspheric lens is inconsistent with the Applicant's specification and is inconsistent with the plain meaning as it would be understood by one of ordinary skill in the art.

For at least the reasons set forth above, Applicant respectfully submits that the Examiner has failed to establish that *Blasingame* anticipates claims 1, 21-24, 26-28, 32, and 42 under 35 U.S.C. § 102(b), and the rejection of those claims should accordingly be withdrawn.

B. Rejection Under 35 U.S.C. § 103

The Examiner rejects claims 17, 18, 25, and 33-40 under 35 U.S.C. § 103 as being unpatentable over *Gaebe*.

1. Claims 25 and 33-40

Claims 25 and 33-40 depend from claim 21 and 32 respectively. If an independent claim is nonobvious under 35 U.S.C. 103, then any claim depending therefrom is nonobvious. *In re Fine*, 837 F.2d 1071 (Fed. Cir. 1988). Therefore, the Applicant requests that the rejections of claims 25 and 33-4 be withdrawn at least for the same reasons as claims 21 and 32 set forth above.

2. Claims 17 and 18

According to the applicable statute, a claimed invention is unpatentable for obviousness if the differences between it and the prior art "are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art." 35 U.S.C. § 103(a) (2005); *Graham v. John Deere Co.*, 383 U.S. 1, 14 (1966); MPEP 2142. Obviousness is a legal question based on underlying factual determinations including: (1) the scope and content of the prior art, including what that prior art teaches explicitly and inherently; (2) the level of ordinary skill in the prior art; (3) the differences between the claimed invention and the prior art; and (4) objective evidence of nonobviousness. *Graham*, 383 U.S. at 17-18; *In*

re Dembiczak, 175 F.3d 994, 998 (Fed. Cir. 1999). It is the initial burden of the PTO to demonstrate a *prima facie* case of obviousness. If the PTO does not set forth a *prima facie* case of obviousness, the applicant is under no obligation to submit evidence of nonobviousness. MPEP 2142.

In rejecting claims 17 and 18, the Examiner sets forth the following on page 8 of the Office Action:

> Gaebe does not suggest that the lenses (32 and 48) are made of any particular material, thereby indicating a lack of criticality in the particular material forming the lenses.
>
> Spherical and aspherical lenses are both known to be formed by either glass and/or plastic materials in the art. Plastic materials provide improved mechanical consistency, lower component manufacturing costs for complicated structures due to molding techniques that are employed in the art, and a reduction in weight, which can reduce additional costs associated with shipping and/or incorporating the elements (in this case lenses) in optical systems. Ball or spherical lenses are simple shapes that are easily made from glass material, which exhibit well known standard properties, and advantageously have improved heat tolerances and offer higher refractive index values when compared to plastics. It is noted that both glass spherical lenses and plastic aspherical senses are well known, commonly used, and readily available in the art.
>
> Therefore, one of ordinary skill in the art would have found it obvious to use a glass ball spherical lens in the invention of Gaebe and thereby provide a lens with well known properties, good heat tolerance, and a high refractive index, since such lenses are well known, commonly used, and readily available in the art. Additionally, one of ordinary skill in the art would have found it obvious to use a plastic aspheric lens in the invention of Gaebe and thereby provide a lens with a more complicated structure that has low manufacturing costs and reduced weight, since such lenses are well known, commonly used, and readily available in the art.

It is error, as here, to reconstruct the Applicant's claimed invention from the prior art by using the patentee's claim as a "blueprint." When prior art references require selective combination to render obvious a subsequent invention, there <u>must be some reason</u> for the combination <u>other than the hindsight obtained from the invention itself</u>. It is critical to understand the particular results achieved by the new combination. *Interconnect Planning Corp v. Feil*, 774 F.2d 1132, 227 USPQ 543 (Fed. Cir. 1985). Simply alleging that such elements are not critical does not carry the Patent Office's burden. Rather, the Examiner must cite to evidence for such proposition. Here, lack of evidence does not prove the Examiner's position.

Although each element of a claim may be known and have known advantages, this does not mean that the combination of elements is obvious as alleged by the Examiner. In fact, the advantages identified by the Examiner would tend to favor a design with two lenses of the same material – that is either glass lenses or plastic lenses, for both lenses. Such advantages do not provide the alleged reason for the particular combination of an aspherical lens comprising a plastic material and a spherical lens comprising a glass material as set forth in the claims. In fact, the only source of record disclosing such a combination of lens materials, and the advantages of the combination of lens materials, resides in the Applicant's specification. "The mere fact that a device or process utilizes a known scientific principle does not alone make that device or process obvious." *Uniroyal, Inc. v. Rudkin-Wiley Corp.*, 837 F.2d 1044 (Fed Cir. 1991). "One cannot use hindsight reconstruction to pick and choose among isolated disclosures in the prior art to deprecate the claimed invention." *In re Fine*, 837 F.2d 1071 (Fed. Cir. 1988). Therefore, the Examiner's rejection of claims 17 and 18 is improper as clearly based on hindsight reconstruction of claims 17 and 18.

In light of the foregoing, Applicant submits that the Examiner has failed to establish a *prima facie* case of obviousness with respect to claim 17 and 18, at least because the Examiner's rejection is based on hindsight reconstruction of the claims. As such, the Applicant respectfully requests that Examiner withdraw the rejection of claims 17 and 18.

CONCLUSION

In view of the foregoing, Applicants believe the claims as amended are in allowable form. In the event that the Examiner finds remaining impediment to a prompt allowance of this application that may be clarified through a telephone interview, or which may be overcome by an Examiner's Amendment, the Examiner is requested to contact the undersigned attorney.

Dated this 2nd day of July, 2007.

Respectfully submitted,

/David A. Jones/ Reg. # 50,004
DAVID A. JONES
Registration No. 50,004
Attorney for Applicant
Customer No. 022913
Telephone: (801) 533-9800

APPENDIX A

Elements of Modern Optical Design, Donald O'Shea, page 216 *(1985)*

difference between the sphere and the asphere at different heights above the optic axis, as shown in Fig. 6.23. First the distance between the plane at the sphere vertex and the sphere is determined. This is referred to as the sagitta or "sag" of the surface at different distances from the optic axis. For a sphere the sag may be written as

$$z_s = \frac{c\rho^2}{1 + \sqrt{1 - c^2\rho^2}}, \tag{6.50}$$

where $c = 1/R$, the curvature of the surface, and $\rho = \sqrt{x^2 + y^2}$, the distance from the optic axis. If c^2 in the denominator of Eq. 6.50 is replaced by $(1 + \kappa)c^2$, the equation gives the sag for an asphere, which is a conic section of revolution, κ is the conic constant ($\kappa = 0$ for a sphere, $\kappa = -1$ for a parabola, $-1 < \kappa < 0$ for ellipsoid, and $\kappa < -1$ for a hyperbola). Depending on the conjugate distances and the presence of other elements in the system, different conic sections are used to construct systems with no spherical aberration. Additional corrections for off-axis aberrations can be made by introducing surfaces that can be represented as higher order polynomials of $c^2\rho^2$ (i.e., $(x^2 + y^2)/R^2$). The added degrees of freedom provided by allowing surfaces to be aspheric must be balanced against the difficulty and increased cost of producing such surfaces.

An example of an aspheric surface in an optical system is the Schmidt corrector plate used for systems with large light-gathering power, such as TV projection systems, missile tracking cameras, and wide-field telescopes. The plate has a fourth-power curve of the form $z_a = \alpha\rho^2 + \beta\rho^4$.

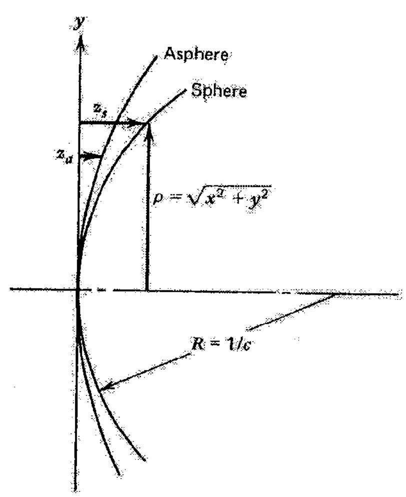


Figure 6.23. Aspheric surface. Definition of an asphere as a departure from a spherical surface.

APPENDIX B

Lens Design Fundamentals, Rudolf Kingslake, pages 2 and 3 (1978)

single piece of glass having polished surfaces, and a complete lens thus contains one or more elements. Sometimes a group of elements, cemented or closely airspaced, is referred to as a "component" of a lens. However, these usages are not standardized and the reader must judge what is meant when these terms appear in a book or article.

I. RELATIONS BETWEEN DESIGNER AND FACTORY

The lens designer must establish good relations with the factory because, after all, the lenses that he designs must eventually be made. He should be familiar with the various manufacturing processes and work closely with the optical engineers. He must always bear in mind that lens elements cost money, and he should therefore use as few of them as possible if cost is a serious factor. Sometimes, of course, image quality is the most important consideration, in which case no limit is placed on the complexity or size of a lens. Far more often the designer is urged to economize by using fewer elements, flatter lens surfaces so that more lenses can be polished on a single block, lower-priced types of glass, and thicker lens elements since they are easier to hold by the rim in the various manufacturing operations.

A. Spherical versus Aspheric Surfaces

In almost all cases the designer is restricted to the use of spherical refracting or reflecting surfaces, regarding the plane as a sphere of infinite radius. The standard lens manufacturing processes[1] generate a spherical surface with great accuracy, but attempts to broaden the designer's freedom by permitting the use of nonspherical or "aspheric" surfaces lead to extremely difficult manufacturing problems; consequently such surfaces are used only when no other solution can be found. The aspheric plate in the Schmidt camera is a classic example. However, molded aspheric surfaces are very practical and can be used wherever the production rate is sufficiently high to justify the cost of the mold; this applies particularly to plastic lenses made by injection molding. Fairly accurate parabolic surfaces can be generated on glass by special machines.

In addition to the problem of generating and polishing a precise aspheric surface, there is the further matter of centering. Centered lenses with spherical surfaces have an optical axis that contains the centers of curvature of all the surfaces, but an aspheric surface has its own independent axis, which must be made to coincide with the axis containing all the other centers of

[1] F. Twyman, "Prism and Lens Making," Hilger and Watts, London, 1952. D. F. Horne, "Optical Production Technology," Crane Russak, New York, 1972.

curvature in the system. Most astronomical instruments and a few photographic lenses and eyepieces have been made with aspheric surfaces, but the designer is advised to avoid such surfaces if at all possible.

B. Establishment of Thicknesses

Negative lens elements should have a center thickness between 6 and 10% of the lens diameter, but the establishment of the thickness of a positive element requires much more consideration. The glass blank from which the lens is made must have an edge thickness of at least 1 mm to enable it to be held during the grinding and polishing operations (Fig. 1). At least 1 mm

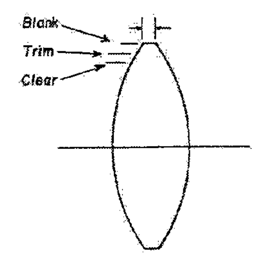


Fig. 1. Assigning thickness to a positive element.

will be removed in edging the lens to its trim diameter, and we must allow at least another 1 mm in radius for support in the mount. With these allowances in mind, and knowing the surface curvatures, the minimum acceptable center thickness of a positive lens can be determined. These specific limitations refer to a lens of average size, say $\frac{1}{2}$ to 3 in. in diameter; they may be somewhat reduced for small lenses, and they must be increased for large ones. A knife-edge lens is very hard to make and handle and it should be avoided wherever possible. A discussion of these matters with the glass-shop foreman can be very profitable.

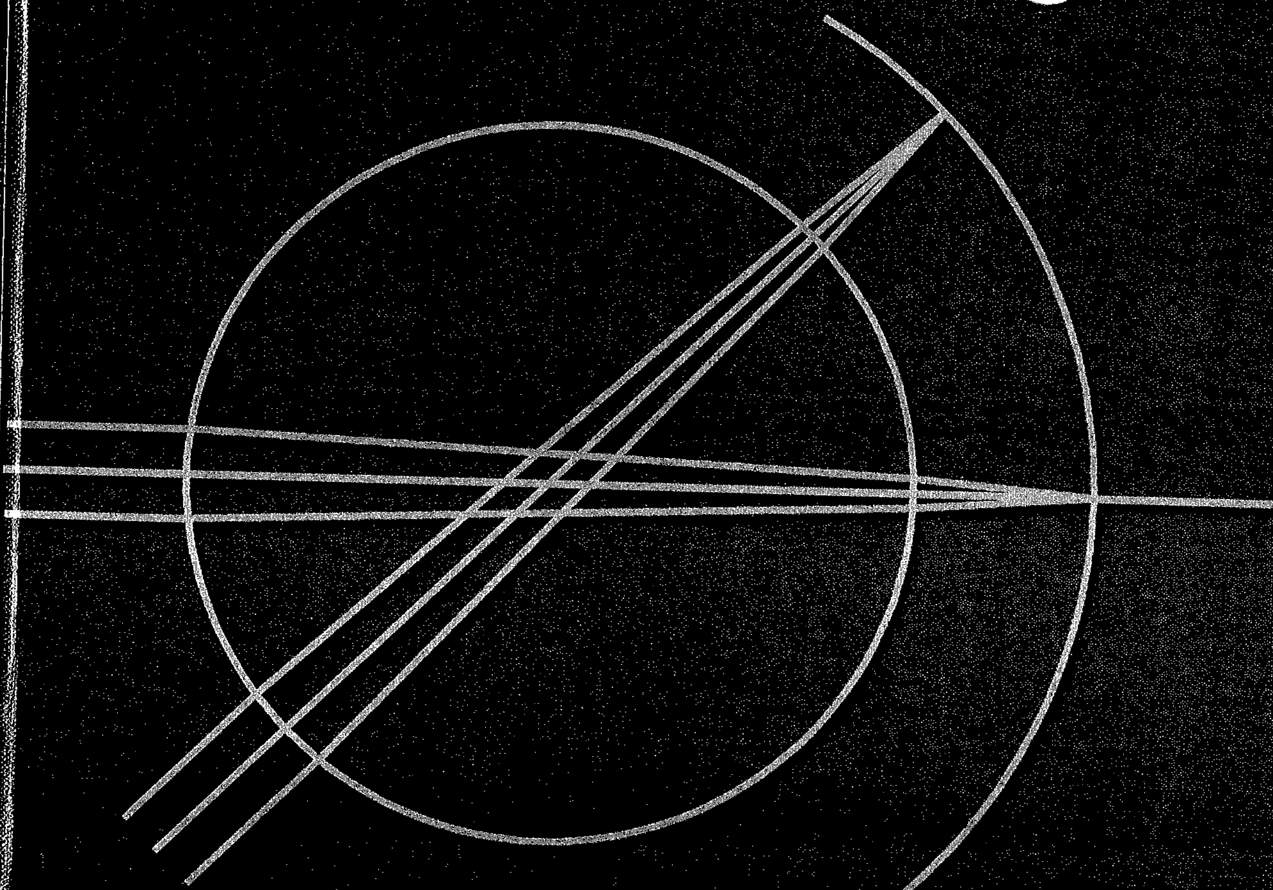
As a general rule, weak lens surfaces are cheaper to make than strong surfaces because more lenses can be polished together on a block. However, if only a single lens is to be made, multiple blocks will not be used, and then a strong surface is no more expensive than a weak one.

A small point but one worth noting is that a lens that is nearly equiconvex is liable to be accidentally cemented or mounted back-to-front in assembly. If possible such a lens should be made exactly equiconvex by a trifling bending, any aberrations so introduced being taken up elsewhere in the system. Another point to notice is that a very small edge separation between two lenses is hard to achieve, and it is better either to let the lenses

APPENDIX C

Fundamental Optical Design, Michael J. Kidger, pages 57-60 and 159-162 (2002)

Fundamental Optical Design



Michael J. Kidger

From Fig. 3.8,

$$\mathbf{s} = \mathbf{p} - e\,\mathbf{r}. \tag{3.43}$$

Since the angles OAH and OHA are equal, and since the sum of the angles OAH and AHD = 180 deg, it follows that

$$\cos(\mathrm{OAH}) = (\mathbf{p} - e\,\mathbf{r}) \cdot \mathbf{c} = -\cos(\mathrm{AHD}) = -(\mathbf{p} - e\,\mathbf{r}) \cdot \mathbf{r}.$$

This then gives

$$e\,\{\mathbf{r} \cdot \mathbf{r} + \mathbf{r} \cdot \mathbf{c}\} = \mathbf{r} \cdot \mathbf{p} + \mathbf{c} \cdot \mathbf{p}, \tag{3.44}$$

and therefore

$$e = \frac{(rp + rc)}{(1 + rc)} = \frac{\left[(L+\bar{L})(x-\bar{x}) + (M+\bar{M})(y-\bar{y}) + (N+\bar{N})(z-\bar{z})\right]}{\left(1 + L\bar{L} + M\bar{M} + N\bar{N}\right)}. \tag{3.45}$$

This expression is therefore used to determine [OA] – [OD]. Note that, if the object is at infinity, OA and OD are both infinite, but e becomes

$$e = L\,(x-\bar{x}) + M\,(y-\bar{y}) + N\,(z-\bar{z}), \tag{3.46}$$

which is finite.

Therefore,

$$W = [\mathrm{FG}] = [\mathrm{OABC}] - [\mathrm{ODEF}] = -n \cdot e + \{[\mathrm{ABC}] - [\mathrm{DEF}]\}, \tag{3.47}$$

which is a simple quantity to compute, and is always finite, as long as the image is at a finite distance.

3.6 Ray tracing through aspheric and toroidal surfaces

In the case of aspheric and toroidal surfaces, it is not possible to find the point of intersection of the ray with the refracting surface analytically, and it is necessary to use an iterative method of some type.

We will not discuss the details of this calculation; rather, we will indicate the general principles followed in aspheric and toroidal ray tracing. Full details of the equations are given by Welford.[2]

An aspheric surface is normally described by the following equation:

$$z = \frac{cr^2}{\left[1 + \sqrt{1 - (1+k)c^2r^2}\right]} + a_4r^4 + a_6r^6 + a_8r^8 + \ldots. \tag{3.48}$$

The first term in this expression is the standard form of a conic surface, Eq. (1.21), but there are extra terms proportional to r^4, r^6, r^8, r^{10},.... In most cases, the power series is not taken beyond the r^{10} term.

A toroidal surface is described by

$$z = r_x \pm \sqrt{\left\{\left[r_x - r_y \pm \sqrt{\left(r_y^{\,2} - y^2\right)}\right]^2 - x^2\right\}}, \tag{3.49}$$

where r_x is the radius of curvature of the surface in the x-z plane and r_y is the radius of curvature of the surface in the y-z plane.

These equations can be written in the form

$$g(x,y,z) = z - \left\{\frac{cr^2}{\left[1+\sqrt{1-(1+k)c^2r^2}\right]} + a_4r^4 + a_6r^6 + a_8r^8 + \ldots\right\} \text{(asphere)} \tag{3.50}$$

and

$$g(x,y,z) = z - \left(r_x \pm \sqrt{\left\{\left[r_x - r_y \pm \sqrt{\left(r_y^{\,2} - y^2\right)}\right]^2 - x^2\right\}}\right) \text{(toroid)}. \tag{3.51}$$

The general method of determining the intersection of a ray with these surfaces, which cannot be handled analytically, is to use an iterative technique, starting at some point that is on the ray but not on the surface.

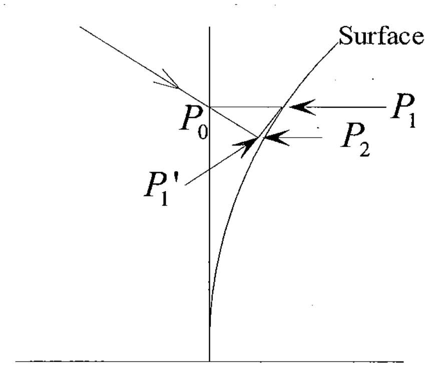


Figure 3.9. Ray tracing through toroids and aspherics.

This point, P_0 in Fig. 3.9, is usually found either by computing the point of intersection with the vertex plane, or by computing the point of intersection of the ray with a spherical or conic surface that is known to be close to the actual surface. Suppose the coordinates of P_0 are x_0, y_0, and z_0. We then calculate the coordinates of a point on the surface, with the same x and y coordinates as P_0, from either Eq. (3.50) or (3.51). This point, P_1, is not on the ray, except in the special case when the ray is parallel to the axis.

Knowing the point P_1, we can find the equation of the tangent plane through P_1, and then we can find the point of intersection of the ray with the tangent plane, P_1'. This point P_1' is generally closer to the surface than the original point P_0. This process is repeated until we have found a point on the ray that is close enough to the surface. For practical purposes, this iterative process can be terminated when the change in ray coordinates between successive approximations is less than about $\lambda/1000$.

In order to find the equation of the tangent plane at P_1, P_2, etc., we need the direction cosines of the normal to the surface, which are found by calculating the partial differentials of $g(x,y,z)$ with respect to x, y, and z, respectively. If these partial differentials are $\partial g/\partial x$, $\partial g/\partial y$, and $\partial g/\partial z$, respectively, the direction cosines will be

$$\alpha = -\frac{\partial g/\partial x}{\sqrt{\left[\left(\partial g/\partial x\right)^2 + \left(\partial g/\partial y\right)^2 + \left(\partial g/\partial z\right)^2\right]}}, \tag{3.52}$$

with similar expressions for β and γ. Since the ray passes through the point P_0, the equation of the ray can be written as

$$\frac{(x-x_0)}{L} = \frac{(y-y_0)}{M} = \frac{(z-z_0)}{N}. \tag{3.53}$$

At the point P_1, with coordinates x_1, y_1 and z_1, the equation of the tangent plane can be written as

$$0 = \alpha(x-x_1) + \beta(y-y_1) + \gamma(z-z_1). \tag{3.54}$$

Solving Eqs. (3.53) and (3.54), we find the coordinates of P_1':

$$z_1' = \frac{N[\alpha(x_1-x_0) + \beta(y_1-y_0) + \gamma z_1]}{[\alpha L + \beta M + \gamma N]}, \tag{3.55}$$

and

$$x_1' = x_0 + \frac{L}{N} z_1' \quad \text{and} \quad y_1' = y_0 + \frac{M}{N} z_1'. \tag{3.56}$$

As stated above, this process is repeated until the points P_i and P_{i+1} are sufficiently close.

For refraction, we use the vector form of Snell's law, Eq. (3.38):

$$\begin{aligned} n'L' &= n\,L + \alpha\,(n'\cos I' - n\cos I) \\ n'M' &= n\,M + \beta\,(n'\cos I' - n\cos I) \\ n'N' &= n\,N + \gamma\,(n'\cos I' - n\cos I), \end{aligned} \tag{3.38}$$

where

$$\cos I = \alpha L + \beta M + \gamma N. \tag{3.31}$$

In practice, these equations typically converge with sufficient accuracy in about five iterations.

3.7 Decentered and tilted surfaces

Although this book is mainly concerned with the design of centered systems, we now discuss the problem of ray tracing through decentered systems. The standard method of defining a decentered surface is to define a set of decentrations, dx, dy, and dz, and a set of rotations, α, β, and γ. (These quantities are not at all related to the direction cosines of the normal to a surface used in the previous section, which are also referred to as α, β, and γ; but this notation is almost standard, and we will not change it.)

When a surface is decentered, we first apply decentrations dx, dy, and dz. If the coordinates of a point, referred to as a "global" axis, are x, y, and z, the coordinates referred to an origin at the decentered vertex of the surface will be

$$\begin{aligned} x' &= x - dx \\ y' &= y - dy \\ z' &= z - dz. \end{aligned} \tag{3.57}$$

We then apply the three rotations, in the order α (clockwise about the x-axis), β (clockwise about the new y-axis), and then γ (anticlockwise about the new z-axis). The three rotations are most simply expressed in matrix notation as follows:

draw the useful distinction between shape-dependent and shape-independent aberrations.

So, for thin lenses away from the stop, the following aberrations are **shape-dependent**:

Spherical aberration
Coma
Astigmatism
Distortion

while the following aberrations are **shape-independent**:

Field curvature (Petzval sum)
Axial color
Lateral color

In many simple systems, the basic layout is determined by the need to correct the three shape-independent aberrations.

The shape-independent aberrations are also unaffected by aspherizing, so it follows that if a lens layout is determined by the need to correct Petzval sum, axial color, or lateral color, the layout will not be affected by the addition of aspheric surfaces.

7.5 Aspheric surfaces

In order to calculate the Seidel aberrations of aspheric surfaces, we first imagine the effect of an aspheric plate, as shown in Fig. 7.10.

Clearly, an aspheric plate, as shown in Fig. 7.10, will introduce an aberration into the output wavefront, and if the asphericity of the aspheric is given by

$$z = a_4 r^4 \tag{7.40}$$

the wavefront aberration is

$$W = a_4 r^4 (n' - n). \tag{7.41}$$

This is, of course, a third-order (Seidel) aberration and can be related to S_1 by the equation

$$S_1 = 8\, a_4 r^4 (n' - n). \tag{7.42}$$

If the aspheric plate is in contact with the aperture stop, there are no other third-order aberrations, since the effect of the obliquity of the beam is to change

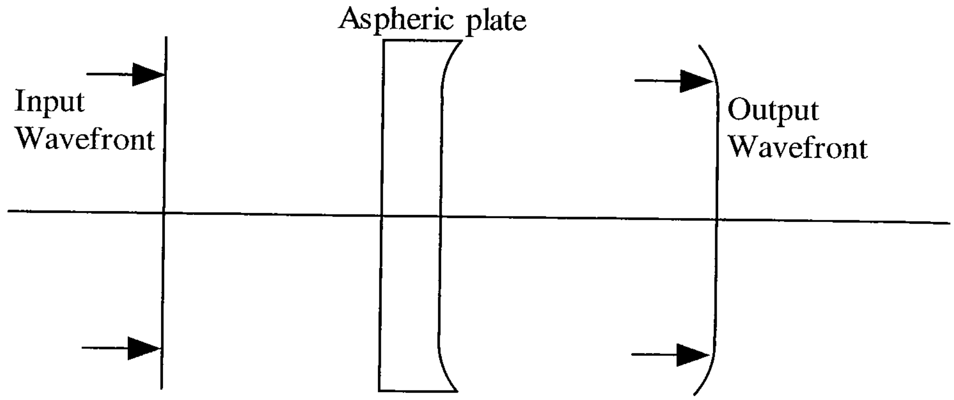


Figure 7.10. Deformation of a wavefront by an aspheric plate.

only higher-order terms. Similarly, the effect of using an aspheric surface on a zero-power meniscus lens is the same as on a plane parallel plate, to the third-order approximation.

When we have a lens with an aspheric surface, we visualize a lens with spherical surfaces, with an aspheric plate in contact with one of the spherical surfaces. The Seidel aberrations of the aspheric lens are then found by computing the aberrations of the spherical lens, and then adding the contributions of the aspheric plate, as shown in Fig. 7.11.

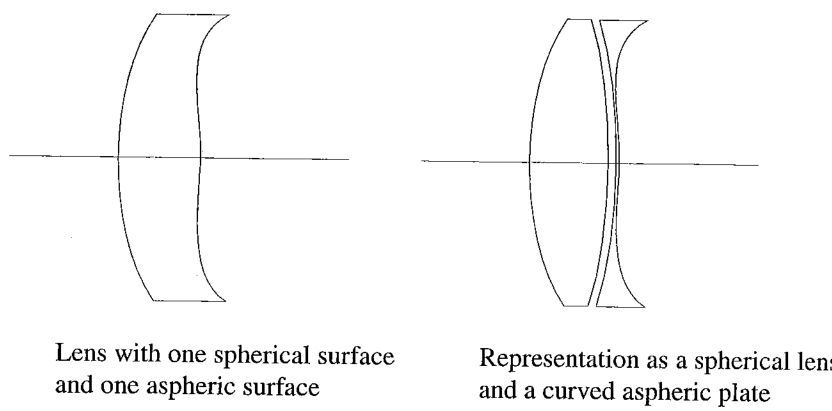


Figure 7.11. Representation of an aspheric lens for Seidel calculations.

Note, however, that there is no need to use this visualization process when actually ray tracing; it is simpler to calculate the geometry of an aspheric surface.

7.5.1 Third-order off-axis aberrations of an aspheric plate

If the aspheric plate is **not at the aperture stop**, the off-axis beams pass obliquely through the aspheric, as shown in Fig. 7.12, and the normal stop-shift effects apply.

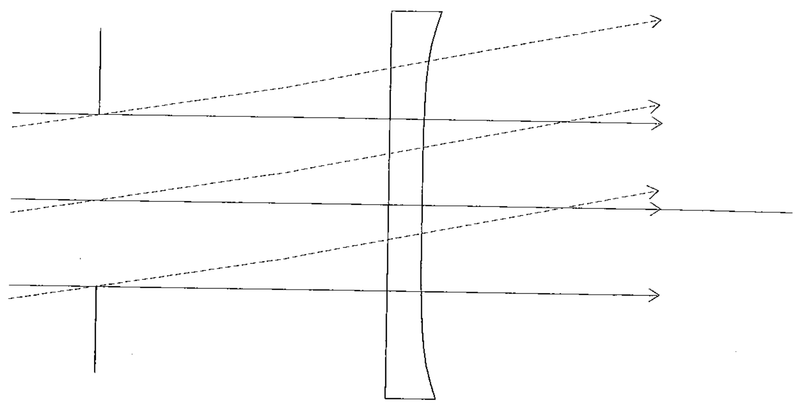


Figure 7.12. Off-axis beam passing through an aspheric plate.

First, recall the quantity, E, described in Sec. 2.5.7 on the Seidel difference formulae. If we have a paraxial chief ray with height $\bar{h}$ at a given surface, a paraxial marginal ray with height h, and a Lagrange invariant H, the stop-shift term E is defined by

$$HE = \frac{\bar{h}}{h}. \tag{2.78}$$

Since E is a measure of the distance of a surface from the aperture stop it will, in general, be different at every surface in the system. Then, if we have an aspheric surface at a non-zero distance from the aperture stop, so that the quantity E is non-zero, the aspheric will introduce off-axis aberrations as follows:

$$\begin{aligned} S_2 &= (HE)S_1 = (HE)8a_4r^4(n'-n) \\ S_3 &= (HE)^2 S_1 = (HE)^2 8a_4r^4(n'-n) \\ S_5 &= (HE)^3 S_1 = (HE)^3 8a_4r^4(n'-n). \end{aligned} \tag{7.43}$$

We can, of course, write these equations in terms of $\bar{h}/h$, to get

$$S_2 = \left(\frac{\bar{h}}{h}\right) S_1 = \left(\frac{\bar{h}}{h}\right) 8a_4 r^4 (n' - n)$$

$$S_3 = \left(\frac{\bar{h}}{h}\right)^2 S_1 = \left(\frac{\bar{h}}{h}\right)^2 8a_4 r^4 (n' - n) \quad \text{(7.4}$$

$$S_5 = \left(\frac{\bar{h}}{h}\right)^3 S_1 = \left(\frac{\bar{h}}{h}\right)^3 8a_4 r^4 (n' - n).$$

Note that the introduction of an aspheric surface has no effect on either the fie curvature term, S_4, or on the first-order chromatic aberration terms.

7.5.2 Chromatic effects

Since the effect of the aspheric is essentially to change the spherical aberratio and possibly to generate stop-shift effects, there are no changes to the Seid chromatic aberration coefficients, C_1 and C_2. There are, however, oth chromatic effects when the aspheric surface is refracting because the refracti index difference $(n' - n)$ will, in general, be a function of wavelength. Therefor in the case of a refracting aspheric surface there will be chromatic variations c S_1, S_2, S_3 and S_5. The chromatic variation of spherical aberration is important i the design of Schmidt cameras, as we shall see in Chapter 13.

7.6 The sine condition

A theorem that was very important in the early development of lens design, bu has been somewhat neglected, is known as the Abbe sine condition.

7.6.1 Sine condition in the finite conjugate case

For a lens corrected for spherical aberration, coma is also corrected if

$$\frac{\sin U'}{u'} = \frac{\sin U}{u}, \quad \text{(7.45}$$

where u' and u are paraxial ray angles, and U' and U are real ray angles. If $n' =$ n, the (paraxial) magnification is given by

$$\text{magnification} = \frac{\eta'}{\eta} = \frac{u}{u'}, \quad \text{(2.33}$$

so it follows that $\sin U / \sin U'$ must equal the magnification, or

APPENDIX D

Lens Design, Milton Laikin, pages 7-10, 195, and 198 (2007)

LENS DESIGN

FOURTH EDITION

MILTON LAIKIN

CRC Press
Taylor & Francis Group

l Areas

5	6	7	8
0.948	0.957	0.964	0.968
0.837	0.866	0.886	0.901
0.707	0.764	0.802	0.829
0.645	0.707	0.750	
0.598	0.661		
0.463	0.559		
		0.267	0.433
			0.250

ect, only one quadrant need be traced. For
il needs to be traced.
trace the minimum number of rays. A
, N, might be equal to 3.
e is $\sqrt{(2(N-J)+1)/2N}$.
omate this process. Generally, the pupil (or in
o rings and the number of rays per ring. Thus,
of rings and the number of rays per ring.
eeds to be traced as well as well as tracing to
ck symmetry, the full pupil must be traced at
ograms today automate this process of ray
ed into rings and each ring into sections.
ecify the number of rings and the number of
es, the ray intercept plots should be carefully
are, then additional rays should be added.
skew orientation, some skew rays should be
les should be such as to divide the image into
s are (the first field angle is axial, $N=1$)

$$= \sqrt{\frac{J}{N-1}}$$

4	5	6
0.5774	0.5	0.4472
0.8165	0.7071	0.6325
1.0	0.8660	0.7746
	1.0	0.8944
		1.0

ASPHERIC SURFACES

Most modern computer programs have the ability to handle aspheric surfaces. For mathematical convenience, surfaces are generally divided into three classes: spheres, conic sections, and general aspheric. The aspheric is usually represented as a tenth-order (or higher order) polynomial. Let X be the surface sag, Y the ray height, and C the curvature of the surface at the optical axis; then

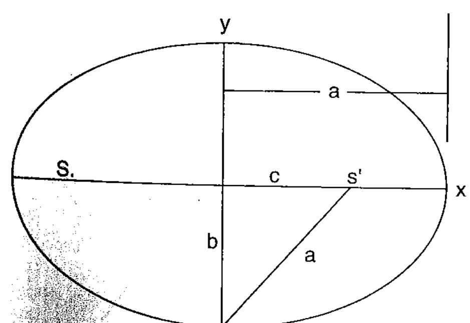
$$X = \frac{CY^2}{1+\sqrt{1-Y^2C^2(1+A_2)}} + AY^4 + A_6Y^6 + A_8Y^8 + A_{10}Y^{10}.$$

This then represents the surface as a deviation from a conic section. A_2 is the conic coefficient and is equal to $-\varepsilon^2$, where ε is the eccentricity as given in most geometry texts.

$A_2 = 0$	sphere
$A_2 < -1$	hyperbola
$A_2 = -1$	parabola
$-1 < A_2 < 0$	ellipse with foci on the optical axis
$A_2 > 0$	ellipse with foci on a line normal to optic axis

CONIC SECTIONS

Ellipse.



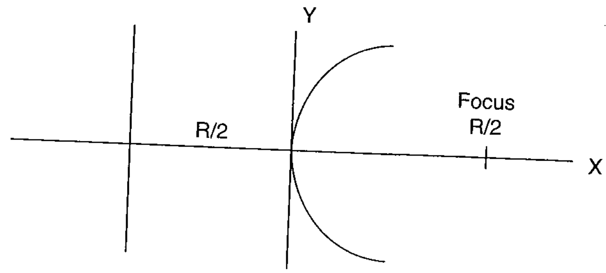
$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1 \quad a^2 = b^2 + c^2$$

$$R \text{ at } y = 0 = \frac{b^2}{a} \qquad M = \frac{S'}{S} = \frac{a+c}{a-c} \quad b = \sqrt{aR}$$

the distance from the origin to the ellipse and θ the angle measured with the X axis:

$$\frac{\cos^2\theta}{a^2} + \frac{\sin^2\theta}{b^2} = \frac{1}{V^2}.$$

Parabola.

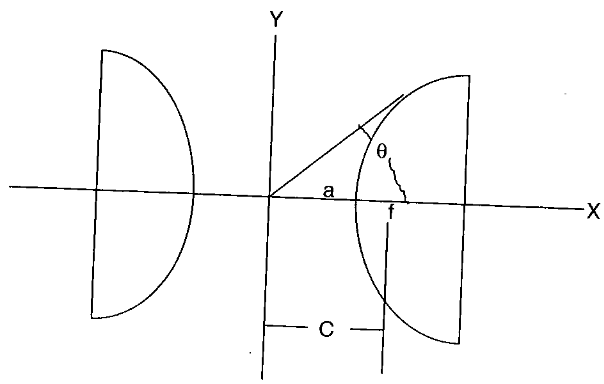


$$Y^2 = 2RX$$

$$\varepsilon = 1$$

$$\text{Radius of curvature} = \frac{(Y^2 + R^2)^{3/2}}{R^2} = R \text{ at } Y = 0$$

Hyperbola.



$$-\varepsilon^2 = -\tan^2\theta - 1.$$

$$\frac{X^2}{A^2} - \frac{Y^2}{B^2} = 1.$$

$$\frac{(x + A)^2}{A^2} - \frac{Y^2}{B^2} = 1.$$

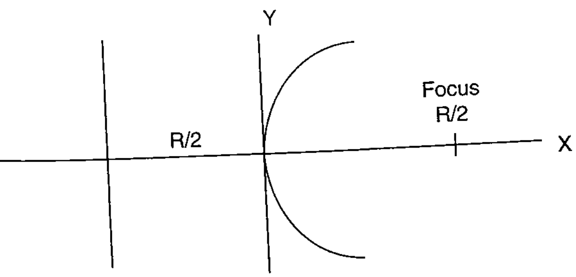
$$C^2 = B^2 + A^2$$

$$\varepsilon = C/A$$

$$R = \frac{B^2}{A} \text{ at } Y = 0.$$

$$\frac{\cos^2\theta}{a^2}+\frac{\sin^2\theta}{b^2}=\frac{1}{V^2}.$$

Parabola.

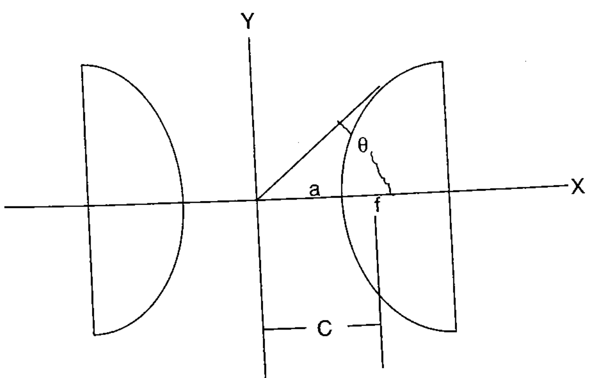


$$Y^2 = 2RX$$

$$\varepsilon = 1$$

$$\text{Radius of curvature} = \frac{(Y^2+R^2)^{3/2}}{R^2} = R \text{ at } Y = 0$$

Hyperbola.



$$-\varepsilon^2 = -\tan^2\theta - 1.$$

$$\frac{X^2}{A^2}-\frac{Y^2}{B^2}=1.$$

$$\frac{(x+A)^2}{A^2}-\frac{Y^2}{B^2}=1.$$

$$C^2 = B^2 + A^2$$

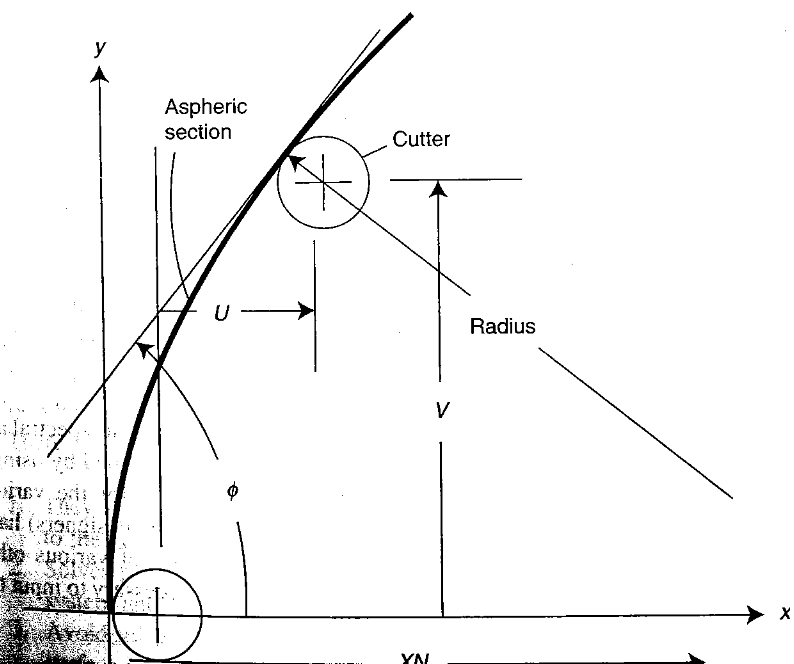
$$\varepsilon = C/A$$

With present technology, it is possible to turn an aspheric surface with single point diamond tooling. This is done with a numerical control system and is being increasingly used for long wavelength infrared systems. In the visual and UV regions, aspherics must be individually polished. The problem is twofold:

1. Most optical polishing machines have motions which tend to generate a spherical surface. (Recently LOH Optical Machinery in Germantown, WI, has made available machines to grind, polish, and test aspheric surfaces.)
2. Aspheric surfaces are very difficult to test.

The best advice concerning aspherics is: unless absolutely necessary, do not use an aspheric surface. Of course, if the lens is to be injection molded, then an aspheric surface is a practical possibility. This is often done in the case of video disc lenses as well as for low cost digital camera lenses (Yamaguchi et al. 2005).

As an aid in manufacturing and testing aspheric surfaces, the author has written a computer program to calculate the surface coordinates as well as the coordinates of a cutter to generate this surface. Let the aspheric surface have coordinates X, Y and be generated by a cutter of diameter D. The coordinates of the center of this cutter are U, V. The cutter is always tangent to the aspheric surface. Referring to Figure 1.1:



$$\tan\phi = \left| \frac{2CY}{1+\sqrt{1-C^2Y^2(1+A_2)}} + \frac{(1+A_2)C^3Y^3}{\left[1+\sqrt{1-C^2Y^2(1+A_2)}\right]^2\sqrt{1-C^2Y^2(1+A_2)}} + 4A_4Y^3 + 6A_6Y^5 + 8A_8Y^7 + 10A_{10}Y^9; \right|$$

$$X = \frac{CY^2}{1+\sqrt{1-Y^2C^2(1+A_2)}} + A_4Y^4 + A_6Y^6 + A_8Y^8 + A_{10}Y^{10};$$

$$U = X + 0.5D\cos\phi - 0.5D;$$

$$V = Y - 0.5D\sin\phi;$$

$$XN = X + \frac{Y}{\tan\phi};$$

$$\text{radius} = \sqrt{Y^2 + (XN - X)^2},$$

where XN is the radius of curvature of the aspheric surface at the optical axis (the paraxial radius of curvature).

REFRACTIAVE INDEX CALCULATIONS

The spectral region of interest should be divided such as to achieve nearly equal refractive index increments. Due to the manner in which refractive index varies for typical optical materials, it is preferable to divide the spectral region in equal frequency regions rather than by wavelength; i.e., it is divided into nearly equal reciprocal wavelength increments.

For MTF calculations, five wavelengths are used (Table 1.2).

Glass catalogs contain index-of-refraction values only at the various spectral and selected laser lines. Calculation at an arbitrary wavelength is performed by using a six-term interpolation formula. The coefficients for this formula for the various glasses are given in the glass catalog. This author (as well as most designers) have the coefficients for the entire glass catalog in addition to those of various other optical materials, stored in a personal computer. It is then only necessary to input the desired wavelengths.

A typical interpolation formula (Schott equation) is

$$N^2 = F_1 + F_2\lambda^2 + F_3\lambda^{-2} + F_4\lambda^{-4} + F_5\lambda^{-6} + F_6\lambda^{-8},$$

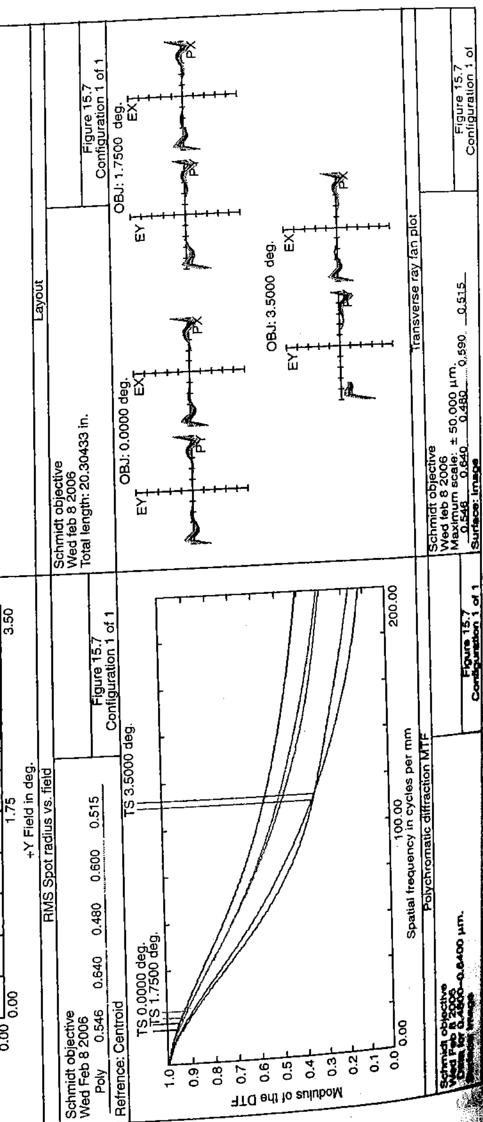


TABLE 15.7
Schmidt Objective

Surface	Radius	Thickness	Material	Diameter
1	0.0000	0.3000	Silica	5.660
2	Stop	20.0000		5.556
3	−20.0000	−9.9980	Mirror	8.141
4	−9.8289	0.0000		1.222

Because the aspheric surface (surface 2) is plane, there is no conic term. The equation for this surface is

$$X = -4.406904 \times 10^{-5} Y^4 - 9.213268 \times 10^{-6} Y^6 + 1.335688 \times 10^{-6} Y^8$$
$$-6.879200 \times 10^{-8} Y^{10}.$$

The disadvantage of this system is the inconvenient position of the image inside the objective as well as its curvature. Its advantage lies in simplicity of construction and its ability to give excellent resolution over a large wavelength region and field of view. A Cassegrain version has been proposed (Baker 1940). This requires an aspheric primary mirror with a spherical secondary. Radii are the same, and therefore a zero Petzval sum with a flat field is obtained. However, the author's experience with this modification has been disappointing. I found it far better to use one of the all-spherical systems as given above.

All of the above systems (with perhaps the exception of the Schmidt system) are telephoto lenses. That is, the overall length of the lens is much less than the effective focal length. They also have relatively short (as a fraction of their focal length) back

TABLE 15.8
Reflecting Objective, *f*/2.5

Surface	Radius	Thickness	Material	Diameter
1	0.0000	1.7946		1.018
2	2.1332	−1.7946	Mirror	0.802 Stop
[illegible]	3.6328	1.7946	Mirror	2.360
[illegible]	2.1332	0.3523	N-K5	1.600
[illegible]	1.5664	0.4190		1.380
6	0.0000	0.1993	SF4	1.360
[illegible]	−23.5725	2.4867		1.360
[illegible]	0.0000	0.0000		0.201

[illegible] from the first surface to image=5.252, distortion=0.11%.

focal lengths. By reversing the role of primary and secondary mirrors, one may obtain an inverted telephoto type of design. Here, the overall length will be substantially longer than the effective focal length and the back focal length will be longer than the effective focal length. This is a useful system for lenses of relatively short focal length, where a long working distance is required. Such an inverted telephoto type of design is shown in Figure 15.8. It is *f*/2.5 and has an image of 0.2 diameter. Details are provided in Table 15.8.

The computer program must have the ability to bound the ray heights at the mirror surfaces. Because there is a hole in the large mirror (surface 2), the first mirror surface must have sufficient curvature to cause the outer rim rays to strike the large mirror outside of this hole. This lens would make an ideal long working distance microscope objective (see Chapter 11). Surface 1 is a central obscuration to block all rays with a height of less than 0.1.

In Figure 15.9 is shown a long effective focal length (250 in.) *f*/10 objective; details are given in Table 15.9. Image size is 1.703, so it is suitable for a 35-mm SLR camera. Both mirrors are hyperbolas, so this may be considered as a modified Ritchey–Chretien design (Rutten 1988). The lens data is given in Table 15.9.

It should be noted here that the usual Cassegrain telescope has a paraboloid primary mirror and a hyperboloid secondary. The Dall–Kirkham telescope has a prolate ellipsoid primary mirror and a spherical secondary. The Richey–Chretien telescope has a hyperboloid primary mirror and a hyperboloid secondary (Schroeder 2000).

Considerable baffling will be required in this system, as well as a spider mechanism to hold the secondary mirror in place. Diffraction effects for this mechanism are not considered in the MTF plot.

To illustrate the importance of the two cemented doublets in the rear, in Figure 15.10 is shown a Ritchey–Chretien design with the same focal length,

TABLE 15.9
A 250-in. Cassegrain Objective

Surface	Radius	Thickness	Material	Diameter
1	−102.3640	−37.8137	Mirror	25.060 Stop
2	−35.3325	48.8327	Mirror	6.910
3	23.5556	0.2500	N-SK16	2.140
4	97.0299	0.3600	LF5	2.140
5	−8.4651	0.3492		2.140
6	−6.0339	0.2500	N-LLF1	1.980
7	2.3002	0.5000	LF5	2.140
8	8.5504	5.4581		1.900
9	0.0000	0.0000		1.705

Distance from secondary mirror to image = 56.000 in., conic coefficient, Surface 1 = −1.075613, conic coefficient, surface 2 = −3.376732.

APPENDIX E

Lens Design Fundamentals, Rudolf Kingslake, pages 2, 3 36-38, and 113 (1978)

LENS DESIGN FUNDAMENTALS

RUDOLF KINGSLAKE

single piece of glass having polished surfaces, and a complete lens thus contains one or more elements. Sometimes a group of elements, cemented or closely airspaced, is referred to as a "component" of a lens. However, these usages are not standardized and the reader must judge what is meant when these terms appear in a book or article.

I. RELATIONS BETWEEN DESIGNER AND FACTORY

The lens designer must establish good relations with the factory because, after all, the lenses that he designs must eventually be made. He should be familiar with the various manufacturing processes and work closely with the optical engineers. He must always bear in mind that lens elements cost money, and he should therefore use as few of them as possible if cost is a serious factor. Sometimes, of course, image quality is the most important consideration, in which case no limit is placed on the complexity or size of a lens. Far more often the designer is urged to economize by using fewer elements, flatter lens surfaces so that more lenses can be polished on a single block, lower-priced types of glass, and thicker lens elements since they are easier to hold by the rim in the various manufacturing operations.

A. Spherical versus Aspheric Surfaces

In almost all cases the designer is restricted to the use of spherical refracting or reflecting surfaces, regarding the plane as a sphere of infinite radius. The standard lens manufacturing processes[1] generate a spherical surface with great accuracy, but attempts to broaden the designer's freedom by permitting the use of nonspherical or "aspheric" surfaces lead to extremely difficult manufacturing problems; consequently such surfaces are used only when no other solution can be found. The aspheric plate in the Schmidt camera is a classic example. However, molded aspheric surfaces are very practical and can be used wherever the production rate is sufficiently high to justify the cost of the mold; this applies particularly to plastic lenses made by injection molding. Fairly accurate parabolic surfaces can be generated on glass by special machines.

In addition to the problem of generating and polishing a precise aspheric surface, there is the further matter of centering. Centered lenses with spherical surfaces have an optical axis that contains the centers of curvature of all the surfaces, but an aspheric surface has its own independent axis, which must be made to coincide with the axis containing all the other centers of

---

[1] F. Twyman, "Prism and Lens Making." Hilger and Watts, London, 1952. D. F. Horne, "Optical Production Technology." Crane Russak, New York, 1972.

curvature in the system. Most astronomical instruments and a few photographic lenses and eyepieces have been made with aspheric surfaces, but the designer is advised to avoid such surfaces if at all possible.

B. Establishment of Thicknesses

Negative lens elements should have a center thickness between 6 and 10% of the lens diameter, but the establishment of the thickness of a positive element requires much more consideration. The glass blank from which the lens is made must have an edge thickness of at least 1 mm to enable it to be held during the grinding and polishing operations (Fig. 1). At least 1 mm

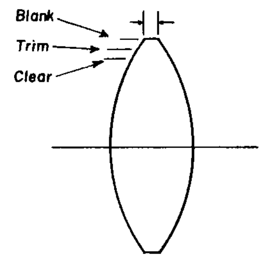


Fig. 1. Assigning thickness to a positive element.

will be removed in edging the lens to its trim diameter, and we must allow at least another 1 mm in radius for support in the mount. With these allowances in mind, and knowing the surface curvatures, the minimum acceptable center thickness of a positive lens can be determined. These specific limitations refer to a lens of average size, say $\frac{1}{2}$ to 3 in. in diameter; they may be somewhat reduced for small lenses, and they must be increased for large ones. A knife-edge lens is very hard to make and handle and it should be avoided wherever possible. A discussion of these matters with the glass-shop foreman can be very profitable.

As a general rule, weak lens surfaces are cheaper to make than strong surfaces because more lenses can be polished together on a block. However, if only a single lens is to be made, multiple blocks will not be used, and then a strong surface is no more expensive than a weak one.

A small point but one worth noting is that a lens that is nearly equiconvex is liable to be accidentally cemented or mounted back-to-front in assembly. If possible such a lens should be made exactly equiconvex by a trifling bending, any aberrations so introduced being taken up elsewhere in the system. Another point to notice is that a very small edge separation between two lenses is hard to achieve, and it is better either to let the lenses

by 1°, we calculate the height at which each emerging ray crosses the paraxial focal plane:

upper marginal ray:	0.147350
axial ray:	0.127870
lower marginal ray:	0.148448

In Fig. 15 we have plotted on a large scale this situation as compared with

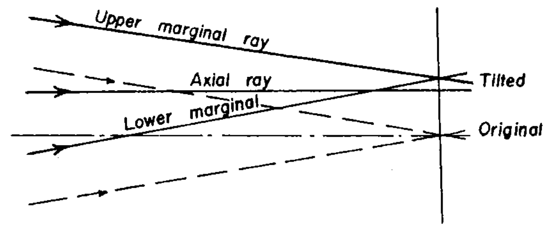


FIG. 15. The result of tilting a lens surface.

the case before the surface was tilted. It is clear that the entire image has been raised, and there is a large amount of coma introduced by the tilting.

VI. RAY TRACING AT AN ASPHERIC SURFACE

An aspheric surface can be defined in several ways, the simplest being to express the sag of the surface from a plane:

$$X = a_2 Y^2 + a_4 Y^4 + a_6 Y^6 + \cdots$$

Only even powers of Y appear because of the axial symmetry. The first term is all that is required for a parabolic surface. To express a sphere in this way we use the power series given in Eq. (9), but a great many terms will be required if the sphere is at all deep.

For many purposes it is better to express the asphere as a departure from a sphere:

$$X = \frac{cY^2}{1 + (1 - c^2 Y^2)^{1/2}} + a_4 Y^4 + a_6 Y^6 + \cdots \tag{13}$$

Here c represents the curvature of the osculating sphere and $a_4, a_6, \ldots$ are the aspheric coefficients.

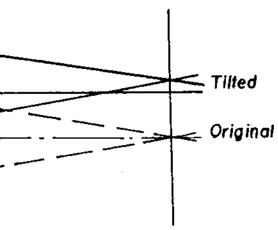
If the surface is known to be a conic section, we may express it by

$$X = \frac{cY^2}{1 + [1 - c^2 Y^2 (1 - e^2)]^{1/2}} \tag{14}$$

h each emerging ray crosses the parax-

l ray: 0.147350
l ray: 0.127870
l ray: 0.148448

e scale this situation as compared with



of tilting a lens surface.

d. It is clear that the entire image has
unt of coma introduced by the tilting.

AN ASPHERIC SURFACE

d in several ways, the simplest being to
plane:

$Y^4 + a_6 Y^6 + \cdots$

se of the axial symmetry. The first term
surface. To express a sphere in this way
q. (9), but a great many terms will be

express the asphere as a departure from

$+ a_4 Y^4 + a_6 Y^6 + \cdots$ (13)

e osculating sphere and $a_4, a_6, \ldots$ are

onic section, we may express it by

$cY^2 / c^2Y^2(1-e^2)]^{1/2}$ (14)

where c is the vertex curvature of the conic and e its eccentricity. The term $1 - e^2$ in this expression is called the "conic constant" since it defines the shape of the surface. Its value is as follows:

Surface	Eccentricity	Conic constant
Hyperbola	> 1	negative
Parabola	1	0
Prolate spheroid (small end of ellipse)	< 1	< 1
Sphere	0	1
Oblate spheroid (side of ellipse)	—	> 1

To trace a ray through an aspheric surface, we must first determine the X and Y coordinates of the point of incidence. The asphere is defined by a relation between X and Y, while the incident ray is defined by its Q and U. Now it is clear from Fig. 16 that

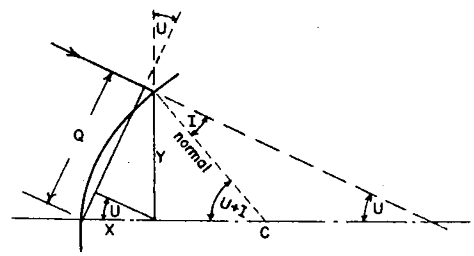


FIG. 16. Ray trace through an aspheric surface.

$$Q = [X] \sin U + Y \cos U$$

where $[X]$ is to be replaced by the expression for the aspheric surface, giving an equation for Y having the same order as the asphere itself.

To solve this equation, we first guess a possible value of Y, say, $Y = Q$. We then evaluate the residual R as follows:

$$R = [X] \sin U + Y \cos U - Q$$

Obviously the correct value of Y is that which makes $R = 0$. Now Newton's rule says that

$$(\text{a better } Y) = (\text{the original } Y) - (R/R')$$

where R' is the derivative of R with respect to Y, namely,

$$R' = (dX/dY) \sin U + \cos U$$

A very few iterations of this formula will give us the value of Y that will make R less than any defined limit, such as 0.00000001. Knowing Y we immediately find X from the equation of the asphere. We then proceed as follows:

The slope of the normal is dX/dY. Hence

$$\tan(U + I) = dX/dY$$
$$\sin I' = (n/n') \sin I$$
$$U' = U + I - I'$$
$$Q' = X \sin U' + Y \cos U'$$

The transfer to the next surface is standard.

This process can be simplified in the case of a surface that is a conic section, because the equation to be solved is then an ordinary quadratic. Note that if the asphere is defined by Eq. (14) the derivative becomes

$$\tan(U + I) = dX/dY = cY/[1 - c^2Y^2(1 - e^2)]^{1/2} \tag{15}$$

Example. Suppose our asphere is given by

$$[X] = 0.1Y^2 + 0.01Y^4 - 0.001Y^6$$

Then

$$dX/dY = 0.2Y + 0.04Y^3 - 0.006Y^5$$

with $n = 1.0$ and $n' = 1.523$. If our entering ray has $U = -10°$ and $Q = 3.0$, then successive iterations of Newton's rule give

	Y	X	dX/dY	R	R'	R/R'
1.	3.0	0.981	0.222	0.124772	1.023358	0.121924
2.	2.878076	0.946119	0.344369	−0.001357	1.044607	−0.001299
3.	2.879375	0.946566	0.343244	0		

Hence

$$\tan(U + I) = (dX/dY) = 0.343244, \qquad U + I = 18.94448°$$

But $U = -10°$. Therefore

$$I = 28.94448°, \qquad I' = 18.52805°$$
$$U' = 0.41644$$
$$Q' = Y \cos U' + X \sin U' = 2.886178$$

Cont'd

c	d	n	Spherical aberration contribution at $f/2$
0.029164			−0.005098
	0.05		
0.113764			+0.005966
	0.3	1.523	
0.077891			0
	0.05		
0.159353			+0.014387
	0.3	1.523	
0.109941			−0.000016
		Total	−0.000068

This lens is shown in Fig. 59. The focal length of the first two lenses is now

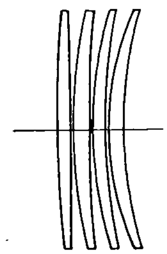


FIG. 59. A four-lens $f/2$ aplanatic objective.

18.380. This system has been used in monochromat microscope objectives made of quartz for use at a single wavelength in the ultraviolet. The design has been discussed by Fulcher.[2]

H. AN ASPHERIC PLANOCONVEX LENS FREE FROM SPHERICAL ABERRATION

Two cases arise, the first when the curved aspheric surface faces the distant object, and the other when the plane surface faces the object.

1. *Convex to the Front*

The image is considered to fall inside the glass, and the situation is indicated in Fig. 60a. By equating optical paths between any finite ray and

[2] G. S. Fulcher, Telescope objective without spherical aberration for large apertures, consisting of four crown glass lenses, *J. Opt. Soc. Am.* **37**, 47 (1947).

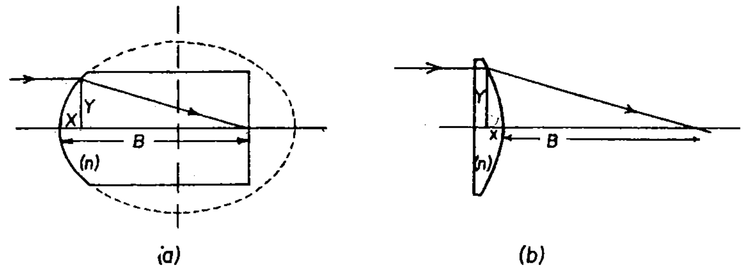


FIG. 60. Aspheric single lenses corrected for spherical aberration.

the axis, we find

$$Bn = X + n[(B - X)^2 + X^2]^{1/2}$$

whence

$$\frac{[X - Bn/(n+1)]^2}{[Bn/(n+1)]^2} + \frac{Y^2}{B^2(n-1)/(n+1)} = 1$$

This is an ellipse with semimajor axis a equal to $Bn/(n+1)$ and semiminor axis b equal to $B[(n-1)/(n+1)]^{1/2}$; the eccentricity $e = [1 - (b/a)^2]^{1/2} = 1/n$. For example, if $B = 20$ mm and $n = 1.5$, the semiaxes become 12.0 and 8.94, respectively, and the vertex radius is 6.66 with $e = 0.6666$. A surface of this kind has long been used on highway reflector "buttons."

2. *Plane Surface in Front*

Equating optical paths in the air behind the lens gives

$$B + nX = [Y^2 + (B + X)^2]^{1/2}$$

whence

$$\frac{\{X + [B/(n+1)]\}^2}{[B/(n+1)]^2} - \frac{Y^2}{B^2(n-1)/(n+1)} = 1$$

There is a clear resemblance between these two cases. The plane-in-front lens has a hyperbolic surface with semimajor axis equal to $B/(n+1)$, and semiminor axis equal to $B[(n-1)/(n+1)]^{1/2}$ as before (Fig. 60b), the eccentricity now being equal to the refractive index n. This surface can be applied on both faces of a biconvex lens for use at finite magnification, up to as high an aperture as required, without any spherical aberration.

APPENDIX F

Modern Lens Design A Resouce Manual, Warren J. Smith, pages 14, 40, 41, 51, and 451

MODERN LENS DESIGN

A Resource Manual

WARREN J. SMITH
GENESEE OPTICS SOFTWARE, INC.

thickness produces only a very small improvement (which is not worth the added cost of producing the thick element). This occurs because the optimization routine will seek out any improvement that it can get, no matter how small, and without concern as to the cost. It is wise to test the value of a thick element if there is any doubt about its utility. This is readily accomplished with another optimization run which fixes the thickness in question to a smaller value. Very often the performance of the thin version will not be noticeably different from that of the "optimum" thicker version. Although most significant with respect to lens thickness, this same rationale obviously applies to airspaces as well.

Aspheric surfaces

Surface asphericity can be an extremely effective (if sometimes expensive) variable, but it is one that often requires a bit of finesse. On occasion, one may be ill-advised to begin an optimization with the conic constant and all the aspheric deformation coefficients used simultaneously as variables. The conic constant and the fourth-order deformation coefficient both affect the third-order aberrations in exactly the same way. Thus they are at least partially redundant, but more significantly, identical variables have an undesirable effect on the mathematics of the optimization process. It is often advisable to vary one or the other, but not both. A safe practice is to vary only the conic constant (or the fourth-order term) at first, and then add the higher-order terms (sixth, eighth, tenth) one at a time, as necessary. The tenth-order term is, in many systems, totally unnecessary, adding little or nothing to the quality of the system; in fact, the eighth-order term is often something that can be done without.

A surface defined by a tenth-order polynomial can cause the spherical aberration to be corrected exactly to zero at four ray heights. If there are only four axial rays in the merit function, their ray intercept errors may all be brought to zero; the danger is that, between these rays, the residual aberration may be unacceptably large. A tenth-order surface can be a rather extreme shape. Thus the use of an aspheric surface sometimes calls for more rays in the merit function than one might otherwise expect to need. With a program which allows wavefront deformation or optical path difference (OPD) targets in the merit function, the severity of this problem can be lessened.

2.8 How to Increase the Speed or Field of a System and Avoid Ray Failure Problems

Very often, the lens designer is faced with the necessity of increasing the speed (i.e., relative aperture, numerical aperture, etc.) and/or the

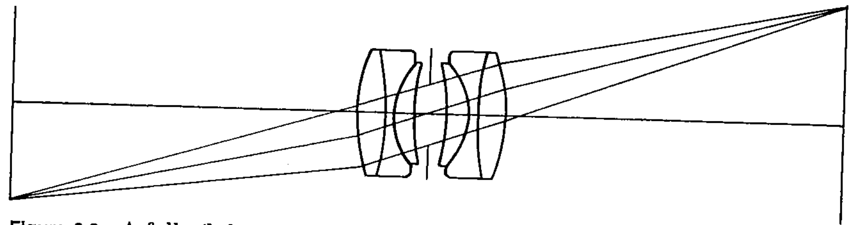


Figure 3.9 A fully (left to right) symmetrical system is completely free of coma, distortion, and lateral color, because the aberration in one half of the system exactly cancels out the aberration in the other half.

with equal object and image distances. For the symmetry to be *absolutely* complete, the object and image surfaces must be identical in shape; this then would imply separately curved sagittal and tangential surfaces at both object and image. However, the third-order coma, distortion, and lateral color are completely removed by symmetry, even with flat object and image surfaces.

Of course, most systems do not operate at unit magnification, and therefore a symmetrical construction of the lens will not completely eliminate these aberrations. However, even for a lens with an infinitely distant object, these aberrations are markedly reduced by symmetry, or even by an approximately symmetrical construction. This is why so many optical systems which cover a significant angular field display a rough symmetry of construction. Consider the Cooke triplet: it has outer crown elements which are similar, but not identical in shape, and the center flint, while not equi-concave, is bi-concave, and, except for slow-speed triplets, the airspaces are quite similar in size. The benefit of this is that the higher-order residuals of coma, distortion, and lateral color are markedly reduced by this symmetry. This is especially true for wide-angle lenses when good distortion correction is important.

3.10 Aspheric Surfaces

Many designs can be improved by the use of one or more aspheric surfaces. Except for the case of a molded or diamond-turned element, an aspheric surface is many times more expensive to fabricate than a spherical surface. A conic aspheric is easier to test than a general aspheric and is therefore somewhat less costly. For many systems, e.g., mirror objectives, aspheric surfaces are essential to the design and cannot be avoided.

One technique for introducing an aspheric into an optical system is to first vary only the conic constant. (Note that the conic constant and

the fourth-order deformation term have exactly the same effect on the third-order aberrations. Thus, allowing both to vary in an automatic design program may cause a slowing of the convergence or, in extreme cases, a failure of the process. Occasionally the difference between the effect of the conic and the fourth-order term on the fifth- and higher-order aberrations may be useful in a design, but more often than not the two are redundant.) If the effect of varying the conic constant alone is inadequate, one can then allow the sixth-order term to vary, then the eighth-order, etc. Some designs have aspherics specified to the tenth-order term when just the sixth or eighth would suffice. It is a good idea to calculate the surface deformation caused by the highest-order term used; if it is a fraction of a wave at the edge of the surface aperture, its utility may well be totally imaginary.

Occasionally one encounters a design specification or print in which the aspheric is specified by a tabulation of sagittal heights instead of an equation. The optimization program can be used to fit the constants of the standard aspheric surface equation to the tabulated data. The specification table is entered in the merit function as the sag of the intersections of (collimated) rays at the appropriate heights. The surface coefficients are allowed to vary, and the result is a least-squares fit to the sag table.

The equations of Sec. F.11 indicate the effects of a conic or a fourth-order aspheric term on the third-order aberrations. Several points are worthy of note. The conic has no effect on the Petzval curvature or on axial or lateral chromatic. Further, if the conic is located at the aperture stop or at a pupil, then the principal ray height, y_p, is zero and the conic has no effect on third-order coma, astigmatism, or distortion; it can only affect third-order spherical. In the Schmidt camera the aspheric surface is located at the stop because the coma and astigmatism are already zero, because the stop is at the center of curvature of the spherical mirror; the purpose of the aspheric is to change *only* the spherical aberration. Conversely, if the purpose of an aspheric is to affect the coma, astigmatism, or distortion, then it must be located a significant distance from the aperture stop.

It is also worth noting that the primary effect of the conic, or fourth-order, deformation term is on the third-order aberrations. The primary effect of the sixth-order deformation term is on the fifth-order aberrations, etc., etc.

F/4.5 25.2deg TRIPLET US 1,987,878/1935 SCHNEIDER

radius	thickness	mat'l	index	V-no	sa
26.160	4.916	LAK12	1.678	55.2	11.7
1201.700	3.988	air			11.7
-83.460	1.038	SF2	1.648	33.8	10.2
25.670	4.000	air			10.2
	6.925	air			9.2
302.610	2.567	LAK22	1.651	55.9	10.3
-54.790	81.433	air			10.3

EFL	= 98.56	= EFFECTIVE FOCAL LENGTH
BFL	= 81.43	= BACK FOCAL LENGTH
NA	= -0.1127 (F/4.4)	= NUMERICAL APERTURE (F-NUMBER)
GIH	= 46.33 (HFOV=25.17)	= IMAGE HEIGHT (HALF FIELD IN DEGREES)
PTZ/F	= -2.831	= (PETZVAL RADIUS)/EFL
VL	= 23.43	= VERTEX LENGTH
OD	infinite conjugate	= OBJECT DISTANCE

Figure 5.1 Sample lens prescription.

With few exceptions, the material names are those of Schott Glass Technologies, Inc. The index and V number values correspond to the wavelengths given with the ray intercept plot (e.g., see Fig. 5.3); for most lenses we have used the *d, F,* and *C* lines. The location of the aperture stop is indicated by a blank in the radius column with air on both sides of the surface. Aspheric surfaces are specified by the conic constant kappa and/or the aspheric deformation coefficients. The equation for the surface is

$$x = \frac{cy^2}{1 + [1 - (1 + \kappa)c^2y^2]^{1/2}} + \mathrm{AD}y^4 + \mathrm{AE}y^6 + \mathrm{AF}y^8 + \mathrm{AG}y^{10} \tag{5.1}$$

The data below the prescription tabulation has the following meanings:

EFL	Effective focal length
BFL	Back focal length (the distance from the last surface to the paraxial focal point)
NA	Numerical aperture (the corresponding f number is in parentheses)
GIH	Gaussian (paraxial) image height (half-field in degrees is in parentheses)
PTZ/F	Petzval radius as a fraction of EFL
VL	Vertex length from first to last surface
OD	Object distance

Lens drawing

A sample lens drawing is shown in Fig. 5.2. The scale of the lens drawing is indicated by the dimensioned length of the line immediately below the lens sketch. The two rays in the sketch are the marginal and principal rays corresponding to the aperture and field angle which are

$$\text{TPC}^* = \text{TPC} \tag{F.10.6}$$

$$\text{DC}^* = \text{DC} + Q(\text{TPC} + 3\text{TAC}) + 3Q^2\text{CC} + Q^3\text{TSC} \tag{F.10.7}$$

$$\text{TAchC}^* = \text{TAchC} \tag{F.10.8}$$

$$\text{TchC}^* = \text{TchC} + Q \cdot \text{TAchC} \tag{F.10.9}$$

F.11 Third-Order Aberrations—Contributions from Aspheric Surfaces

Determine the contributions from the spherical surface or element, then add the following to determine the total contribution from the aspheric surface or element.

$$K = \text{equivalent fourth-order deformation coefficient}$$

$$= \frac{\text{conic constant } \kappa}{8r^3} \quad \text{for pure conic sections}$$

$$= \frac{\kappa}{8r^3} \text{ plus the fourth-order deformation coefficient for conics with aspheric deformations}$$

$$W = \frac{4K(n' - n)}{hn_k'u_k'} \qquad (hn_k'u_k' = \text{the invariant})$$

$$\text{TSC}_a = Wy^4h \tag{F.11.1}$$

$$\text{CC}_a = Wy^3y_ph \tag{F.11.2}$$

$$\text{TAC}_a = Wy^2y_p^2h \tag{F.11.3}$$

$$\text{TPC}_a = 0 \tag{F.11.4}$$

$$\text{DC}_a = Wyy_p^3h \tag{F.11.5}$$

$$\text{TAchC}_a = 0 \tag{F.11.6}$$

$$\text{TchC}_a = 0 \tag{F.11.7}$$

F.12 Conversion of Aberrations to Wavefront Deformation (OPD, Optical Path Difference)

The following expressions convert aberrations to peak-to-peak or peak-to-valley wavefront deformations, when the reference point is chosen to minimize the OPD. Note that for low-order aberrations, rms OPD and peak-to-valley (P-V) OPD are related by

APPENDIX G

Mirriam-Webster's Collegiate Dictionary, pages 73 and 1200 (11th Ed. 2003)

Merriam-Webster's Collegiate® Dictionary

Eleventh Edition

®

aspect ratio *n* (1907) : a ratio of one dimension to another: as **a** : the ratio of span to mean chord of an airfoil **b** : the ratio of the width of a television or motion-picture image to its height

as·pen \ˈas-pən\ *n* [ME, of an aspen, fr. *asp* aspen, fr. OE *æspe;* akin to OHG *aspa* aspen, Russ *osina*] (1593) : any of several poplars (esp. *Populus tremula* of Europe and *P. tremuloides* and *P. grandidentata* of No. America) with leaves that flutter in the lightest wind because of their flattened petioles

as per \ˈaz-ˌpər\ *prep* (1782) : in accordance with : ACCORDING TO ⟨*as per* your instructions⟩ — **as per usual** : as usual

As·per·ger's syndrome \ˈäs-ˌpər-gərz-\ *n* [Hans *Asperger* †1980 Austrian pediatrician] (1989) : a developmental disorder resembling autism that is characterized by impaired social interaction, by restricted and repetitive behaviors and activities, and by normal language and cognitive development — called also *Asperger's disorder*

as·per·ges \ə-ˈspər-(ˌ)jēz\ *n* [L, thou wilt sprinkle, fr. *aspergere*] (ca. 1587) : a ceremony of sprinkling altar and people with holy water

as·per·gil·lo·sis \ˌas-pər-(ˌ)ji-ˈlō-səs\ *n, pl* **-lo·ses** \-ˌsēz\ (1898) : infection with or disease caused (as in poultry) by aspergillus molds

as·per·gil·lum \ˌas-pər-ˈji-ləm\ *n, pl* **-la** \-lə\ *or* **-lums** [NL, fr. L *aspergere*] (1649) : a brush or small perforated container with a handle that is used for sprinkling holy water in a liturgical service

as·per·gil·lus \-ˈji-ləs\ *n, pl* **-gil·li** \-ˈji-ˌlī\ [NL, genus name, fr. *aspergillum*] (1862) : any of a genus (*Aspergillus*) of ascomycetous fungi with branched radiate sporophores including many common molds

as·per·i·ty \a-ˈsper-ə-tē, ə-, -ˈspe-rə-\ *n, pl* **-ties** [ME *asprete,* fr. AF *aspreté,* fr. *aspre* rough, fr. L *asper,* fr. OL **absperos,* fr. *ab-* ab- + *-speros;* akin to Skt *apasphura* repelling, L *spernere* to spurn — more at SPURN] (13c) **1** : RIGOR, SEVERITY **2 a** : roughness of surface : UNEVENNESS; *also* : a tiny projection from a surface **b** : roughness of sound **3** : roughness of manner or of temper : HARSHNESS ⟨asked with some ~ just what they were implying⟩

as·perse \ə-ˈspərs, a-\ *vt* **as·persed; as·pers·ing** [L *aspersus,* pp. of *aspergere,* fr. *ad-* + *spargere* to scatter — more at SPARK] (15c) **1** : SPRINKLE; *esp* : to sprinkle with holy water **2** : to attack with evil reports or false or injurious charges ***syn*** see MALIGN

as·per·sion \ə-ˈspər-zhən, -shən\ *n* (ca. 1587) **1** : a sprinkling with water esp. in religious ceremonies **2 a** : a false or misleading charge meant to harm someone's reputation ⟨cast ~*s* on her integrity⟩ **b** : the act of making such a charge : DEFAMATION

[1]**as·phalt** \ˈas-ˌfȯlt *also* ˈash-, *esp Brit* -ˌfalt\ *also* **as·phal·tum** \as-ˈfȯl-təm, *esp Brit* -ˈfal-\ *n* [ME *aspalt,* fr. LL *aspaltus,* fr. Gk *asphaltos*] (14c) **1** : a dark bituminous substance that is found in natural beds and is also obtained as a residue in petroleum refining and that consists chiefly of hydrocarbons **2** : an asphaltic composition used for pavements and as a waterproof cement — **as·phal·tic** \as-ˈfȯl-tik, *esp Brit* -ˈfal-\ *adj*

[2]**asphalt** *vt* (ca. 1859) : to cover with asphalt : PAVE 1

asphalt jungle *n* (1920) : a big city or a specified part of a big city

aspher·ic \(ˌ)ā-ˈsfir-ik, -ˈsfer-\ *or* **aspher·i·cal** \-i-kəl\ *adj* (ca. 1922) : departing slightly from the spherical form esp. in order to correct for spherical aberration ⟨an ~ lens⟩

as·pho·del \ˈas-fə-ˌdel\ *n* [L *asphodelus,* fr. Gk *asphodelos*] (1597) : any of various Old World herbs (esp. genera *Asphodelus* and *Asphodeline*) of the lily family with flowers in usu. long erect racemes

as·phyx·ia \as-ˈfik-sē-ə, əs-\ *n* [NL, fr. Gk, stopping of the pulse, fr. *a-* + *sphyzein* to throb] (1778) : a lack of oxygen or excess of carbon dioxide in the body that results in unconsciousness and often death and is usu. caused by interruption of breathing or inadequate oxygen supply

as·phyx·i·ate \-sē-ˌāt\ *vb* **-at·ed; -at·ing** *vt* (1836) : to cause asphyxia in ~ *vi* : to become asphyxiated — **as·phyx·i·a·tion** \-ˌfik-sē-ˈā-shən\ *n*

[1]**as·pic** \ˈas-pik\ *n* [MF, alter. of *aspe,* fr. L *aspis*] (1530) *obs* : [2]ASP

[2]**aspic** *n* [F, lit., asp] (1789) : a clear savory jelly (as of fish or meat stock) used as a garnish or to make a meat, fish, or vegetable mold

as·pi·dis·tra \ˌas-pə-ˈdis-trə\ *n* [NL, irreg. fr. Gk *aspid-, aspis* shield] (1822) : an Asian plant (*Aspidistra elatior*) of the lily family that has large pointed basal leaves and is often grown as a foliage plant

[1]**as·pi·rant** \ˈas-p(ə-)rənt, ə-ˈspī-rənt\ *n* (1738) : one who aspires ⟨presidential ~*s*⟩

[2]**aspirant** *adj* (1800) : seeking to attain a desired position or status ⟨the pilot was an ~ astronaut⟩

[1]**as·pi·rate** \ˈas-p(ə-)rət\ *n* (1617) **1** : an independent sound \h\ or a character (as the letter *h*) representing it **2** : a consonant having aspiration as its final component ⟨in English the \p\ of *pit* is an ~⟩ **3** : material removed by aspiration

[2]**as·pi·rate** \ˈas-pə-ˌrāt\ *vt* **-rat·ed; -rat·ing** [L *aspiratus,* pp. of *aspirare*] (ca. 1700) **1** : to pronounce (a vowel or a consonant) with aspiration (sense 1a) **2 a** : to draw by suction **b** : to remove (as blood) by aspiration **c** : to take into the lungs by aspiration

as·pi·ra·tion \ˌas-pə-ˈrā-shən\ *n* (14c) **1 a** : audible breath that accompanies or comprises a speech sound **b** : the pronunciation or addition of an aspiration; *also* : the symbol of an aspiration **2** : a drawing of something in, out, up, or through by or as if by suction: as **a** : the act of breathing and esp. of breathing in **b** : the withdrawal of fluid or tissue from the body **c** : the taking of foreign matter into the lungs with the respiratory current **3 a** : a strong desire to achieve something high or great **b** : an object of such desire ***syn*** see AMBITION — **as·pi·ra·tion·al** \-ˈrā-sh(ə-)nəl\ *adj*

as·pi·ra·tor \ˈas-pə-ˌrā-tər\ *n* (1804) : an apparatus for producing suction or moving or collecting materials by suction; *esp* : a hollow tubular instrument connected with a partial vacuum and used to remove fluid or tissue or foreign bodies from the body

as·pire \ə-ˈspī(-ə)r\ *vi* **as·pired; as·pir·ing** [ME, fr. MF or L; MF *aspirer,* fr. L *aspirare,* lit., to breathe upon, fr. *ad-* + *spirare* to breathe] (14c) **1** : to seek to attain or accomplish a particular goal ⟨*aspired* to a career in medicine⟩ **2** : ASCEND, SOAR — **as·pir·er** *n*

as·pi·rin \ˈas-p(ə-)rən\ *n, pl* **aspirin** *or* **aspirins** [ISV, fr. *a*cetyl + *spi*raeic acid (former name of salicylic acid), fr. NL *Spiraea,* genus of shrubs — more at SPIREA] (1899) **1** : a white crystalline derivative $C_9H_8O_4$ of salicylic acid used for relief of pain and fever **2** : a tablet of aspirin

ASR *abbr* **1** airport surveillance radar **2** air-sea rescue

as regards *also* **as respects** *prep* (1633) : in regard to : with respect to ⟨*as regards* our previous discussion⟩

[1]**ass** \ˈas\ *n* [ME, fr. OE *assa,* prob. fr. OIr *asan,* fr. L *asinus*] (bef. 12c) **1** : any of several hardy gregarious African or Asian perissodactyl mammals (genus *Equus*) smaller than the horse and having long ears; *esp* : an African mammal (*E. asinus*) that is the ancestor of the donkey **2** *sometimes vulgar* : a stupid, obstinate, or perverse person ⟨made an ~ of himself⟩ — often compounded with a preceding adjective ⟨don't be a smart-*ass*⟩

[2]**ass** \ˈas\ *or* **arse** \ˈas, ˈärs\ *n* [ME *ars, ers,* fr. OE *ærs, ears;* akin to OHG & ON *ars* buttocks, Gk *orrhos* buttocks, *oura* tail] (bef. 12c) **1 a** *often vulgar* : BUTTOCKS — often used in emphatic reference to a specific person ⟨get your ~ over here⟩ ⟨saved my ~⟩ **b** *often vulgar* : ANUS **2** *usu vulgar* : SEXUAL INTERCOURSE

[3]**ass** *adv* [[2]*ass*] (ca. 1920) *often vulgar* — used as a postpositive intensive esp. with words of derogatory implication ⟨fancy-*ass*⟩

as·sai \ä-ˈsī\ *adv* [It, fr. VL **ad satis* enough — more at ASSET] (ca. 1724) : VERY — used with tempo direction in music ⟨allegro ~⟩

as·sail \ə-ˈsāl\ *vt* [ME, fr. AF *assaillir,* fr. VL **assalire,* alter. of L *assilire* to leap upon, fr. *ad-* + *salire* to leap — more at SALLY] (13c) : to attack violently with blows or words ***syn*** see ATTACK — **as·sail·able** \-ˈsā-lə-bəl\ *adj* — **as·sail·ant** \-ˈsā-lənt\ *n*

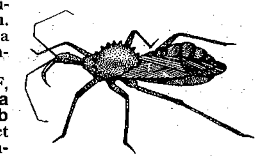
As·sam \ə-ˈsam, a-\ *n* [*Assam,* India] (1842) : a black tea grown in northeastern India

As·sam·ese \ˌa-sə-ˈmēz, -ˈmēs\ *n, pl* **Assamese** (1826) **1** : a native or inhabitant of Assam, India **2** : the Indo-Aryan language of Assam — **Assamese** *adj*

as·sas·sin \ə-ˈsa-sᵊn\ *n* [ML *assassinus,* fr. Ar *ḥashshāshīn,* pl. of *ḥashshāsh* worthless person, lit., hashish user, fr. *hashīsh* hashish] (ca. 1520) **1** *cap* : a member of a Shia Muslim sect who at the time of the Crusades was sent out on a suicidal mission to murder prominent enemies **2** : a person who commits murder; *esp* : one who murders a politically important person either for hire or from fanatical motives

as·sas·si·nate \ə-ˈsa-sə-ˌnāt\ *vt* **-nat·ed; -nat·ing** (1607) **1** : to injure or destroy unexpectedly and treacherously **2** : to murder (a usu. prominent person) by sudden or secret attack often for political reasons ***syn*** see KILL — **as·sas·si·na·tion** \-ˌsa-sə-ˈnā-shən\ *n* — **as·sas·si·na·tor** \-ˈsa-sə-ˌnā-tər\ *n*

assassin bug *n* (1895) : any of a family (Reduviidae) of bugs that are usu. predatory on insects though some (as a kissing bug) suck the blood of mammals — called also *reduviid*



assassin bug

[1]**as·sault** \ə-ˈsȯlt\ *n* [ME *assaut,* fr. AF, fr. VL **assaltus,* fr. *assalire*] (14c) **1 a** : a violent physical or verbal attack **b** : a military attack usu. involving direct combat with enemy forces **c** : a concerted effort (as to reach a goal or defeat an adversary) **2 a** : a threat or attempt to inflict offensive physical contact or bodily harm on a person (as by lifting a fist in a threatening manner) that puts the person in immediate danger of or in apprehension of such harm or contact — compare BATTERY 1b **b** : RAPE 2

[2]**assault** *vt* (15c) **1** : to make an assault on **2** : RAPE 2 ~ *vi* : to make an assault ***syn*** see ATTACK — **as·sault·er** *n*

assault boat *n* (1941) : a small portable boat used in an amphibious military attack or in land warfare for crossing rivers or lakes

as·saul·tive \ə-ˈsȯl-tiv\ *adj* (1946) **1** : of, relating to, or tending toward assault ⟨~ behavior⟩ **2** : having an intense or abrasive effect on the senses or emotions ⟨loud and ~ music⟩ — **as·saul·tive·ly** *adv* — **as·saul·tive·ness** *n*

assault rifle *n* (1972) : any of various automatic or semiautomatic rifles with large capacity magazines designed for military use

assault weapon *n* (1973) : any of various automatic or semiautomatic firearms; *esp* : ASSAULT RIFLE

[1]**as·say** \ˈa-ˌsā, a-ˈsā\ *n* [ME, fr. AF *assai, essai* — more at ESSAY] (14c) **1** *archaic* : TRIAL, ATTEMPT **2** : examination and determination as to characteristics (as weight, measure, or quality) **3** : analysis (as of an ore or drug) to determine the presence, absence, or quantity of one or more components; *also* : a test used in this analysis **4** : a substance to be assayed; *also* : the tabulated result of assaying

[2]**as·say** \a-ˈsā, ˈa-ˌsā\ *vt* (14c) **1** : TRY, ATTEMPT **2 a** : to analyze (as an ore) for one or more specific components **b** : to judge the worth of : ESTIMATE ~ *vi* : to prove up in an assay — **as·say·er** *n*

assed \ˈast\ *adv* (1923) *often vulgar* : [3]ASS — used in combination ⟨sorry-*assed* state of affairs⟩

as·se·gai *or* **as·sa·gai** \ˈa-si-ˌgī\ *n* [ultim. fr. Ar *al-zaghāya* the assegai, fr. *al-* the + Berber *zaghāya* spear] (1600) : a slender hardwood spear or light javelin usu. tipped with iron and used in southern Africa

as·sem·blage \ə-ˈsem-blij, *for 3 also* ˌa-ˌsäm-ˈbläzh\ *n* (1690) **1** : a collection of persons or things : GATHERING **2** : the act of assembling : the state of being assembled **3 a** : an artistic composition made from scraps, junk, and odds and ends (as of paper, cloth, wood, stone, or metal) **b** : the art of making assemblages

as·sem·blag·ist \-bli-jist, -ˈblä-zhist\ *n* (1965) : an artist who specializes in assemblages

as·sem·ble \ə-ˈsem-bəl\ *vb* **as·sem·bled; as·sem·bling** \-b(ə-)liŋ\ [ME, fr. AF *assembler,* fr. VL **assimulare,* fr. L *ad-* + *simul* together — more at SAME] *vt* (13c) **1** : to bring together (as in a particular place or for a particular purpose) **2** : to fit together the parts of ~ *vi* : to meet together : CONVENE ***syn*** see GATHER

as·sem·bler \-b(ə-)lər\ *n* (1616) **1** : one that assembles **2 a** : a computer program that automatically converts instructions written in assembly language into machine language **b** : ASSEMBLY LANGUAGE

as·sem·bly \ə-ˈsem-blē\ *n, pl* **-blies** [ME *assemblee,* fr. AF, fr. *assembler*] (14c) **1** : a company of persons gathered for deliberation and leg-

[1]**spelt** \'spelt\ *n* [ME, fr. OE, fr. LL *spelta*, of Gmc origin; perh. akin to MHG *spelte* split piece of wood, OHG *spaltan* to split — more at SPLIT] (bef. 12c) : an ancient wheat (*Triticum spelta* syn. *T. aestivum spelta*) with spikelets containing two light red grains; *also* : the grain of spelt

[2]**spelt** \'spelt\ *chiefly Brit past and past part of* SPELL

spel·ter \'spel-tər\ *n* [prob. alter. of MD *speauter*] (1661) : ZINC; *esp* : zinc cast in slabs for commercial use

spe·lunk·er \spi-'ləŋ-kər, 'spē-ˌ\ *n* [L *spelunca* cave, fr. Gk *spēlynx*; akin to Gk *spēlaion* cave] (1942) : one who makes a hobby of exploring and studying caves

spe·lunk·ing \-kiŋ\ *n* (1944) : the hobby or practice of exploring caves

spence \'spen(t)s\ *n* [ME, fr. AF *espence, spence*, fr. ML *expensa* victuals, fr. LL, outlay, compulsory supply of food — more at EXPENSE] (14c) *dial chiefly Brit* : PANTRY

[1]**spen·cer** \'spen(t)-sər\ *n* [George John, 2d earl *Spencer* †1834 Eng. politician] (1795) : a short waist-length jacket

[2]**spencer** *n* [prob. fr. the name *Spencer*] (1840) : a trysail abaft the foremast or mainmast

Spen·ce·ri·an \spen-'sir-ē-ən\ *adj* [Platt R. *Spencer* †1864 Am. calligrapher] (1862) : of or relating to a form of slanting handwriting

Spen·ce·ri·an·ism \spen-'sir-ē-ə-ˌni-zəm\ *n* (1881) : the synthetic philosophy of Herbert Spencer that has as its central idea the mechanistic evolution of the cosmos from relative simplicity to relative complexity

spend \'spend\ *vb* **spent** \'spent\; **spend·ing** [ME, fr. OE *-spendan*, fr. ML *expendere* to disburse, use up, fr. L, to measure by weight, pay out — more at EXPEND] *vt* (13c) **1** : to use up or pay out : EXPEND **2 a** : EXHAUST, WEAR OUT ⟨the hurricane gradually *spent* itself⟩ **b** : to consume wastefully : SQUANDER ⟨the waters are not ours to ~ —J. R. Ellis⟩ **3** : to cause or permit to elapse : PASS ⟨~ the night⟩ **4** : GIVE UP, SACRIFICE ~ *vi* **1** : to expend or waste wealth or strength **2** : to become expended or consumed **3** : to have an orgasm — **spend·able** \'spen-də-bəl\ *adj* — **spend·er** *n*

spending money *n* (15c) : POCKET MONEY

spend·thrift \'spen(d)-ˌthrift\ *n* (1584) : a person who spends improvidently or wastefully — **spendthrift** *adj*

spendy \'spen-dē\ *adj* **spend·i·er; -est** (1985) *chiefly Northwest* : EXPENSIVE

Spen·gle·ri·an \ˌshpeŋ-'glir-ē-ən, ˌspeŋ-, -'lir-\ *adj* (1922) : of or relating to the theory of world history developed by Oswald Spengler which holds that all major cultures undergo similar cyclical developments from birth to maturity to decay — **Spenglerian** *n*

Spen·se·ri·an stanza \spen-'sir-ē-ən-\ *n* [Edmund *Spenser*] (1817) : a stanza consisting of eight verses of iambic pentameter and an alexandrine with a rhyme scheme *ababbcbcc*

spent \'spent\ *adj* [ME, fr. pp. of *spenden* to spend] (15c) **1 a** : used up : CONSUMED **b** : exhausted of active or required components or qualities often for a particular purpose ⟨~ nuclear fuel⟩ **2** : drained of energy or effectiveness : EXHAUSTED **3** : exhausted of spawn or sperm ⟨~ fishes⟩

sperm \'spərm\ *n, pl* **sperm** *or* **sperms** [ME, fr. MF *esperme, sperme*, fr. LL *spermat-, sperma*, fr. Gk, lit., seed, fr. *speirein* to sow; prob. akin to Arm *p'aratem* I dispense] (14c) **1 a** : SEMEN **b** : a male gamete; *esp* : SPERMATOZOON **1** **2** : a product of the sperm whale

sperm- *or* **spermo-** *or* **sperma-** *or* **spermi-** *comb form* [Gk *sperm-, spermo-*, fr. *sperma*] : seed : germ : sperm ⟨*sperma*theca⟩ ⟨*spermi*cide⟩

sper·ma·ce·ti \ˌspər-mə-'sē-tē, -'se-\ *n* [ME *sperma cete*, fr. ML *sperma ceti* whale sperm] (15c) : a waxy solid obtained from the oil of cetaceans and esp. from a closed cavity in the heads of sperm whales and used esp. formerly in ointments, cosmetics, and candles

sper·ma·go·ni·um \ˌspər-mə-'gō-nē-əm\ *n, pl* **-nia** \-nē-ə\ [NL] (1861) : a flask-shaped or depressed receptacle in which spermatia are produced in some fungi and lichens

sper·ma·ry \'spər-mə-rē, 'spərm-rē\ *n, pl* **-ries** [NL *spermarium*, fr. Gk *sperma*] (ca. 1859) : an organ in which male gametes are developed

spermat- *or* **spermato-** *comb form* [Gk, fr. *spermat-, sperma*] : seed : spermatozoon ⟨*spermat*id⟩ ⟨*spermato*cyte⟩

sper·ma·the·ca \ˌspər-mə-'thē-kə\ *n* [NL] (1826) : a sac for sperm storage in the female reproductive tract of various lower animals and esp. insects

sper·mat·ic \(ˌ)spər-'ma-tik\ *adj* (15c) **1** : relating to sperm or a spermary **2** : resembling, carrying, or full of sperm

spermatic cord *n* (1783) : a cord that suspends the testis within the scrotum and contains the vas deferens and vessels and nerves of the testis

sper·ma·tid \'spər-mə-təd\ *n* (1889) : one of the haploid cells that are formed by the second division in meiosis of a spermatocyte and that differentiate into spermatozoa

sper·ma·ti·um \(ˌ)spər-'mā-sh(ē-)əm\ *n, pl* **-tia** \-sh(ē-)ə\ [NL, fr. Gk *spermation*, dim. of *spermat-, sperma*] (1856) : a nonmotile male gamete of a red alga; *also* : a nonmotile cell functioning as a male gamete in certain fungi and lichens — **sper·ma·tial** \-sh(ē-)əl\ *adj*

sper·mato·cyte \(ˌ)spər-'ma-tə-ˌsīt\ *n* (1886) : a cell giving rise to sperm cells; *esp* : a cell that is derived by mitosis from a spermatogonium and ultimately gives rise by meiosis to four haploid spermatids

sper·mato·gen·e·sis \(ˌ)spər-ˌma-tə-'je-nə-səs\ *n* [NL] (1881) : the process of male gamete formation including formation of a spermatocyte from a spermatogonium, meiotic division of the spermatocyte, and transformation of the four resulting spermatids into spermatozoa — **sper·mato·gen·ic** \-'je-nik\ *adj*

sper·mato·go·ni·um \-'gō-nē-əm\ *n, pl* **-nia** \-nē-ə\ [NL] (1861) : a primitive male germ cell — **sper·mato·go·ni·al** \-nē-əl\ *adj*

sper·mato·phore \(ˌ)spər-'ma-tə-ˌfōr\ *n* [ISV] (ca. 1849) : a capsule, packet, or mass enclosing spermatozoa that is extruded by the male of various lower animals (as insects) and is transferred to the reproductive tract of the female

sper·mato·phyte \-ˌfīt\ *n* [ultim. fr. NL *spermat-* + Gk *phyton* plant — more at PHYT-] (1897) : any of a group (Spermatophyta) of higher plants comprising those that produce seeds and including the gymnosperms and angiosperms — **sper·mato·phyt·ic** \-ˌma-tə-'fi-tik\ *adj*

sper·ma·to·zo·an \(ˌ)spər-ˌma-tə-'zō-ən, ˌspər-mə-tə-\ *n* (ca. 1900) : SPERMATOZOON — **spermatozoan** *adj*

sper·ma·to·zo·id \-'zō-əd\ *n* [ISV, fr. NL *spermatozoon*] (1854) : a motile male gamete of a plant usu. produced in an antheridium

sper·ma·to·zo·on \-'zō-ˌän, -'zō-ən\ *n, pl* **-zoa** \-'zō-ə\ [NL] (ca. 1839) **1** : a motile male gamete of an animal usu. with rounded or elongate head and a long posterior flagellum **2** : SPERMATOZOID — **sper·ma·to·zo·al** \-'zō-əl\ *adj*

sperm cell *n* (1851) : SPERM 1b

sper·mi·cide \'spər-mə-ˌsīd\ *n* (1929) : a preparation or substance (as nonoxynol-9) used to kill sperm — **sper·mi·cid·al** \ˌspər-mə-'sī-dəl\ *adj*

sper·mio·gen·e·sis \ˌspər-mē-ō-'je-nə-səs\ *n* [NL, fr. *spermium* spermatozoon + *-o-* + L *genesis*] (1916) : SPERMATOGENESIS; *specif* : transformation of a spermatid into a spermatozoon

sperm nucleus *n* (1887) : either of two nuclei that derive from the generative nucleus of a pollen grain and function in the fertilization of a seed plant

sperm oil *n* (1839) : a pale yellow oil from the sperm whale

sper·mo·phile \'spər-mə-ˌfī(-ə)l\ *n* [ultim. fr. Gk *sperma* seed + *philos* loving] (1824) : GROUND SQUIRREL

sperm whale \'spərm-\ *n* [short for *spermaceti whale*] (ca. 1700) : a large toothed whale (*Physeter macrocephalus* syn. *P. catodon*) with a massive squarish head having a large closed cavity containing a fluid mixture of spermaceti and oil

-spermy *n comb form* [Gk *sperma* seed, sperm] : state of exhibiting or resulting from (such) a fertilization ⟨agamo*spermy*⟩

sper·ry·lite \'sper-i-ˌlīt\ *n* [Francis L. *Sperry*, †1906 Am. chemist + E *-lite*] (1889) : a mineral consisting of an arsenide of platinum

spes·sar·tite \'spe-sər-ˌtīt\ *or* **spes·sar·tine** \-ˌtēn\ *n* [F, fr. *Spessart* mountain range, Germany] (1850) : a manganese aluminum garnet usu. containing other elements (as iron) in minor amounts

[1]**spew** \'spyü\ *vb* [ME, fr. OE *spīwan*; akin to OHG *spīwan* to spit, L *spuere*, Gk *ptyein*] *vi* (bef. 12c) **1** : VOMIT **2** : to come forth in a flood or gush **3** : to ooze out as if under pressure : EXUDE ~ *vt* **1** : VOMIT **2** : to send or cast forth with vigor or violence or in great quantity ⟨a volcano ~*ing* out ash⟩ — often used with *out* — **spew·er** *n*

[2]**spew** *n* (15c) **1** : matter that is vomited : VOMIT **2** : material that exudes or is extruded

SPF *abbr* sun protection factor

sp gr *abbr* specific gravity

sphag·nous \'sfag-nəs\ *adj* (ca. 1828) : of, relating to, or abounding in sphagnum

sphag·num \'sfag-nəm\ *n* [NL, fr. L *sphagnos*, a moss, fr. Gk] (1741) **1** : any of an order (Sphagnales, containing a single genus *Sphagnum*) of atypical mosses that grow only in wet acid areas where their remains become compacted with other plant debris to form peat **2** : a mass of sphagnum plants

sphagnum 1

sphal·er·ite \'sfa-lə-ˌrīt\ *n* [G *Sphalerit*, fr. Gk *sphaleros* deceitful, fr. *sphallein* to cause to fall; fr. its often being mistaken for galena — more at SPILL] (ca. 1868) : a mineral composed essentially of zinc sulfide that is the most important ore of zinc — called also *zinc blende*

S phase *n* [*s*ynthesis] (1966) : the period in the cell cycle during which DNA replication takes place — compare G_1 PHASE, G_2 PHASE, M PHASE

sphene \'sfēn\ *n* [F *sphène*, fr. Gk *sphēn* wedge] (1815) : a mineral that is a silicate of calcium and titanium and often contains other elements

sphen·odon \'sfē-nə-ˌdän, 'sfe-\ *n* [NL, genus name, fr. Gk *sphēn* wedge + *odōn, odous* tooth — more at TOOTH] (1878) : TUATARA — **sphen·odont** \-ˌdänt\ *adj*

[1]**sphe·noid** \'sfē-ˌnȯid\ *or* **sphe·noi·dal** \sfi-'nȯi-dəl\ *adj* [NL *sphenoides*, fr. Gk *sphēnoeidēs* wedge-shaped, fr. *sphēn* wedge] (1732) **1** : of, relating to, or being a winged compound bone of the base of the cranium **2** *usu sphenoidal* : having a wedged shape

[2]**sphenoid** *n* (1828) : a sphenoid bone

sphe·nop·sid \sfi-'näp-səd\ *n* [ultim. fr. Gk *sphēn* wedge + NL *-opsis*] (1957) : any of a class or division (Sphenopsida or Sphenophyta) of primitive vascular plants characterized by jointed ribbed stems, small leaves usu. in whorls at distinct stem nodes, and sporangia in sporangiophores and made up of the horsetails and extinct related forms

spher- *or* **sphero-** *also* **sphaer-** *or* **sphaero-** *comb form* [NL *sphaer-*, fr. Gk *sphair-, sphairo-*, fr. *sphaira* sphere] : sphere ⟨*spher*ule⟩ ⟨*sphero*meter⟩

spher·al \'sfir-əl\ *adj* (1545) **1** : SPHERICAL **2** : of or relating to the spheres of ancient astronomy

[1]**sphere** \'sfir\ *n* [ME *spere* globe, celestial sphere, fr. AF *espere*, fr. L *sphaera*, fr. Gk *sphaira*, lit., ball; perh. akin to Gk *spairein* to quiver — more at SPURN] (14c) **1 a (1)** : the apparent surface of the heavens of which half forms the dome of the visible sky **(2)** : any of the concentric and eccentric revolving spherical transparent shells in which according to ancient astronomy stars, sun, planets, and moon are set **b** : a globe depicting such a sphere; *broadly* : GLOBE a **2 a** : a globular body : BALL **b** : PLANET, STAR **c (1)** : a solid that is bounded by a surface consisting of all points at a given distance from a point constituting its center — see VOLUME table **(2)** : the bounding surface of a sphere **3** : natural, normal, or proper place; *esp* : social order or rank ⟨not in the same ~ as his moneyed friends⟩ **4 a** *obs* : ORBIT **b** : an area or range over or within which someone or something acts, exists, or has influence or significance ⟨the public ~⟩ — **spher·ic** \'sfir-ik, 'sfer-\ *adj, archaic* — **sphe·ric·i·ty** \sfir-'i-sə-tē\ *n*

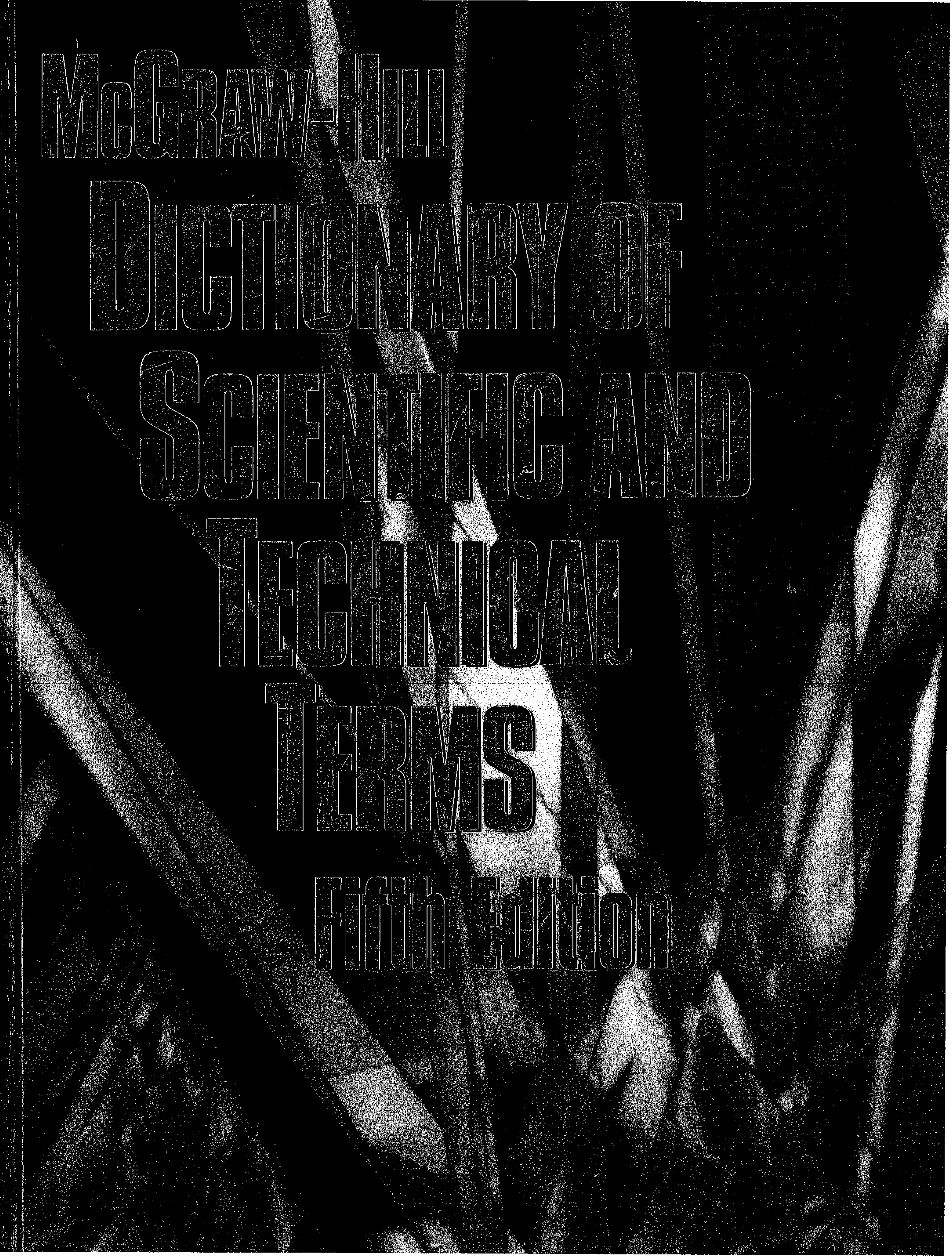
[2]**sphere** *vt* **sphered; spher·ing** (1602) **1** : to place in a sphere or among the spheres : ENSPHERE **2** : to form into a sphere

sphere of influence (1885) : a territorial area within which the political influence or the interests of one nation are held to be more or less paramount

spher·i·cal \'sfir-i-kəl, 'sfer-\ *adj* (15c) **1** : having the form of a sphere or of one of its segments **2** : relating to or dealing with a sphere or its properties — **spher·i·cal·ly** \-k(ə-)lē\ *adv*

spherical aberration *n* (1868) : aberration that is caused by the spherical form of a lens or mirror and that gives different foci for central and marginal rays

spherical angle *n* (1678) : the angle between two intersecting arcs of great circles of a sphere measured by the plane angle formed by the tangents to the arcs at the point of intersection


McGraw-Hill
Dictionary of
Scientific and
Technical
Terms
Fifth Edition

ture of 88–92% crushed stone with the balance asphalt cement. { 'aˌsfȯlt ˌbläk }

asphalt cement [MATER] Fluxed or unfluxed asphalt especially prepared for direct use in making bituminous pavements. { 'aˌsfȯlt si'ment }

asphalt cutter [MECH ENG] A powered machine having a rotating abrasive blade; used to saw through bituminous surfacing material. { 'aˌsfȯlt ˌkəd·ər }

asphalt emulsion [MATER] Asphalt cement in water containing a small amount of emulsifying agent. { 'aˌsfȯlt i'məl·shən }

asphalt-emulsion slurry seal [MATER] A mixture of slow-setting emulsified asphalt, fine aggregate, and mineral filler, with water added to produce a slurry consistency. { 'aˌsfȯlt i'məl·shən 'slə·rē ˌsēl }

asphalt enamel [MATER] A surface coating composed of a mixture of asphalt, finely pulverized mica, clay, soapstone, or talc; applied to pipe that will be buried. { 'aˌsfȯlt i'nam·əl }

asphaltene [MATER] Any of the dark, solid constituents of crude oils and other bitumens which are soluble in carbon disulfide but insoluble in paraffin naphthas; they hold most of the organic constituents of bitumens. { a'sfȯlˌtēn }

asphalt flux [MATER] An oil used to reduce the consistency or viscosity of hard asphalt to the point required for use. { 'aˌsfȯlt ˌfləks }

asphalt fog seal [MATER] An asphalt surface treatment consisting of a light application of liquid asphalt without a mineral aggregate cover. { 'aˌsfȯlt ¦fäg ˌsēl }

asphalt heater [ENG] A piece of equipment for raising the temperature of bitumen used in paving. { 'aˌsfȯlt 'hēd·ər }

asphaltic base oil [MATER] A crude oil that has asphaltum as the predominating solid residual. { a'sfȯlt·ik ¦bās ˌȯil }

asphaltic concrete [MATER] A special concrete consisting of a mixture of graded aggregate and heated asphalt; must be applied and spread while hot. { a'sfȯlt·ik 'känˌkrēt }

asphaltic material [MATER] A solid, liquid, or semisolid mixture of heavy hydrocarbons and nonmetallic derivatives; obtained from naturally occurring bituminous deposits or from residues of petroleum refining. { a'sfȯl·tik mə'tir·ē·əl }

asphaltic road oil [MATER] A thick, fluid solution of asphalt. { a'sfȯlt·ik 'rōd ˌȯil }

asphaltic sand [GEOL] Deposits of sand grains cemented together with soft, natural asphalt. { a'sfȯlt·ik 'sand }

asphaltite [GEOL] Any of the dark-colored, solid, naturally occurring bitumens that are insoluble in water, but more or less completely soluble in carbon disulfide, benzol, and so on, with melting points between 250 and 600°F (121–316°C); examples are gilsonite and grahamite. { a'sfȯlˌtīt }

asphaltite coal *See* albertite. { a'sfȯlˌtīt ˌkōl }

asphalt lamination [MATER] A laminate of sheet material, such as paper or felt, which uses asphalt as the adhesive. { 'aˌsfȯlt ˌlam·ə'nā·shən }

asphalt leveling course [CIV ENG] A layer of an asphalt-aggregate mixture of variable thickness, used to eliminate irregularities in contour of an existing surface, prior to the placement of a superimposed layer. { 'aˌsfȯlt 'lev·əl·iŋ ˌkȯrs }

asphalt macadam [MATER] Pavement made with an asphalt binder rather than tar. { 'aˌsfȯlt mə'kad·əm }

asphalt mastic [MATER] A mixture of asphalt with sand, asbestos, crushed rock, or similar material; used like cement. Also known as mastic asphalt. { 'aˌsfȯlt 'mas·tik }

asphalt overlay [CIV ENG] One or more layers of asphalt construction on an existing pavement. { 'aˌsfȯlt 'ov·ərˌlā }

asphalt paint [MATER] Asphaltic material dissolved in volatile solvent with or without pigments, drying oils, resins, and so on. { 'aˌsfȯlt ¦pānt }

asphalt paper [MATER] A paper that is coated or impregnated with asphalt. { 'aˌsfȯlt 'pā·pər }

asphalt pavement [CIV ENG] A pavement consisting of a surface layer of mineral aggregate, coated and cemented together with asphalt cement on supporting layers. { 'aˌsfȯlt 'pāv·mənt }

asphalt primer [MATER] Low-viscosity, liquid asphaltic material applied to and absorbed by nonbituminous surfaces, as in waterproofing. { 'aˌsfȯlt 'prīm·ər }

asphalt rock [GEOL] Natural asphalt-containing sandstone or dolomite. Also known as asphalt stone; bituminous rock; rock asphalt. { 'aˌsfȯlt 'räk }

asphalt roofing [MATER] A roofing material made by impregnating a dry roofing felt with a hot asphalt saturant, app asphalt coatings to the weather and reverse sides, and embe a mineral surfacing in the coating on the weather side. { 'a 'rüf·iŋ }

asphalt shingle [MATER] A roof shingle made of fe pregnated with asphalt and covered with mineral gra { 'aˌsfȯlt 'shiŋ·gəl }

asphalt soil stabilization [CIV ENG] The treatment of rally occurring nonplastic or moderately plastic soil with asphalt at normal temperatures to improve the load-be qualities of the soil. { 'aˌsfȯlt ¦sȯil ˌstāb·ə·lə'zā·shən }

asphalt stone *See* asphalt rock. { 'aˌsfȯlt 'stōn }

asphalt tile [MATER] Floor tile composed of asbestos f mineral coloring pigments, and inert fillers bound together; on rigid subfloors or hardwood floors. { 'aˌsfȯlt 'tīl }

asphaltum [MATER] Bituminous material in oil of turpe used in photomechanical work because of its ability to be dered insoluble in light. { a'sfȯl·təm }

aspheric surface [OPTICS] A lens or mirror surface wh altered slightly from a spherical surface in order to reduc errations. { ā'sfir·ik 'sər·fəs }

asphradium [INV ZOO] An organ, believed to be a ch receptor, in mollusks. Also spelled osphradium. { a'sfr əm }

asphyxia [MED] Suffocation due to oxygen deprivatio sulting in anoxia and carbon dioxide accumulation in the b { a'sfik·sē·ə }

aspiculate [INV ZOO] Lacking spicules, referring to Pori { a'spik·yə·lət }

Aspidiotinae [INV ZOO] A subfamily of homopteran in in the superfamily Coccoidea. { aˌspid·ē'ä·təˌnē }

Aspidiphoridae [INV ZOO] An equivalent name for the Sp didae. { aˌspid·ə'fȯr·əˌdē }

Aspidobothria [INV ZOO] An equivalent name for the A dogastrea. { ¦as·pəˌdō'bäth·rē·ə }

Aspidobothroidea [INV ZOO] A group of trematodes corded class rank by W. J. Hargis. { ¦as·pəˌdō·bə'thrȯid·ē

Aspidobranchia [INV ZOO] An equivalent name for the chaeogastropoda. { ¦as·pəˌdō'braŋk·ē·ə }

Aspidochirotacea [INV ZOO] A subclass of bilaterally s metrical echinoderms in the class Holothuroidea characte by tube feet and 10–30 shield-shaped tentacles. { ¦as·pəˌd rə'tās·ē·ə }

Aspidochirotida [INV ZOO] An order of holothurioid e noderms in the subclass Aspidochirotacea characterized by piratory trees and dorsal tube feet converted into tactile w { ¦as·pəˌdōˌkī'räd·ə·də }

Aspidocotylea [INV ZOO] An equivalent name for the A dogastrea. { ¦as·pəˌdōˌkäd·ə'lē·ə }

Aspidodiadematidae [INV ZOO] A small family of deep echinoderms in the order Diadematoida. { ¦as·pəˌdō də'mad·əˌdē }

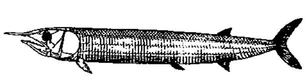
Aspidogastrea [INV ZOO] An order of endoparasitic wo in the class Trematoda having strongly developed ventral h fasts. { ¦as·pəˌdō'gas·trē·ə }

Aspidogastridae [INV ZOO] A family of trematode worm the order Aspidogastrea occurring as endoparasites of mollu { ¦as·pəˌdō'gas·trəˌdē }

Aspidorhynchidae [PALEON] The single family of Aspidorhynchiformes, an extinct order of holostean fis { ¦as·pəˌdō'riŋ·kəˌdē }

Aspidorhynchiformes [PALEON] A small, extinct orde specialized holostean fishes. { ¦as·pəˌdōˌriŋk·ə'fȯrˌmēz }

ASPIDORHYNCHIFORMES



Aspidorhynchus acutirostris (Blainville), Upper Jurassic, Bavaria, length to 3 feet (91 centimeters).

aspidospermine [PHARM] $C_{22}H_{30}O_2N_2$ White to brow yellow crystals with a melting point of 132–136°C; solubl water, alcohol, chloroform, and ether; used in medicine. { pəˌdō'spərˌmēn }

Aspinothoracida [PALEON] The equivalent name Brachythoraci. { aˌspīn·ō·thə'ras·əd·ə }

aspirating *See* dedusting. { 'as·pəˌrād·iŋ }

aspirating burner [ENG] A burner in which combustion at high velocity is drawn over an orifice, creating a nega static pressure and thereby sucking fuel into the stream of the mixture of air and fuel is conducted into a combustion cha ber, where the fuel is burned in suspension. { 'as·pəˌrād·iŋ nər }

aspirating screen [MIN ENG] A vibrating screen from wh light, liberated particles are removed by suction. { 'as·pə iŋ 'skrēn }

pterygopalatine ganglion and the sphenopalatine branch of the maxillary artery. { ˌsfē·nō'pal·əˌtēn fə'rā·mən }

sphenoparietal index [ANTHRO] The ratio, multiplied by 100, of the breadth of the skull from stenion to stenion to its greatest breadth. { ¦sfē·nō·pə'rī·əd·əl 'inˌdeks }

Sphenyllopsida [PALEOBOT] An extinct class of embryophytes in the division Equisetophyta. { ˌsfēn·əl'äp·səd·ə }

Sphenopsida [BOT] A group of vascular cryptogams characterized by whorled, often very small leaves and by the absence of true leaf gaps in the stele; essentially equivalent to the division Equisetophyta. { sfə'näp·səd·ə }

spherator [PL PHYS] One of the class of low-β, low-density, quasi-steady-state closed devices (like Tokamak) used in studying production of electric power by fusion. { 'sfeˌrād·ər }

sphere [MATH] **1.** The set of all points in a euclidean space which are a fixed common distance from some given point; in euclidean three-dimensional space the Riemann sphere consists of all points (x,y,z) which satisfy the equation $x^2+y^2+z^2=1$. **2.** The set of points in a metric space whose distance from a fixed point is constant. { sfir }

sphere gap [ELEC] A spark gap between two equal-diameter spherical electrodes. { 'sfir ˌgap }

sphere of attraction [PHYS CHEM] The distance within which the potential energy arising from mutual attraction of two molecules is not negligible with respect to the molecules' average thermal energy at room temperature. { 'sfir əv ə'trak·shən }

sphere photometer *See* integrating-sphere photometer. { 'sfir fō'täm·əd·ər }

spheres of Eudoxus [ASTRON] A theory of Eudoxus from about 400 B.C.; the planets, sun, and moon were on a series of concentric spheres rotating inside one another on different axes. { 'sfirz əv yü'däk·səs }

spherical aberration [OPTICS] Aberration arising from the fact that rays which are initially at different distances from the optical axis come to a focus at different distances along the axis when they are reflected from a spherical mirror or refracted by a lens with spherical surfaces. { 'sfir·ə·kəl ˌab·ə'rā·shən }

spherical angle [MATH] The figure formed by the intersection of two great circles on a sphere, and equal in size to the angle formed by the tangents to the great circles at the point of intersection. { ¦sfir·ə·kəl 'aŋ·gəl }

spherical antenna [ELECTROMAG] An antenna having the shape of a sphere, used chiefly in theoretical studies. { 'sfir·ə·kəl an'ten·ə }

spherical Bessel functions [MATH] Bessel functions whose order is half of an odd integer; they arise as the radial functions that result from solving Pockel's equation (or, equivalently, the time-independent Schrödinger equation for a free particle) by separation of variables in spherical coordinates. { ¦sfir·i·kəl 'bes·əl ˌfəŋk·shənz }

spherical capacitor [ELEC] A capacitor made of two concentric metal spheres with a dielectric filling the space between the spheres. { 'sfir·ə·kəl kə'pas·əd·ər }

spherical-coordinate robot [CONT SYS] A robot in which the degrees of freedom of the manipulator arm are defined primarily by spherical coordinates. { 'sfir·ə·kəl kō¦ȯrd·ən·ət 'rōˌbät }

spherical coordinates [MATH] A system of curvilinear coordinates in which the position of a point in space is designated by its distance r from the origin or pole, called the radius vector, the angle ϕ between the radius vector and a vertically directed polar axis, called the cone angle or colatitude, and the angle θ between the plane of ϕ and a fixed meridian plane through the polar axis, called the polar angle or longitude. Also known as spherical polar coordinates. { 'sfir·ə·kəl kō'ȯrd·ən·əts }

spherical curve [MATH] A curve that lies entirely on the surface of a sphere. { 'sfir·ə·kəl 'kərv }

spherical cyclic curve *See* cyclic curve. { 'sfir·ə·kəl 'sī·klik 'kərv }

spherical degree [MATH] A solid angle equal to one-ninetieth of a spherical right angle. { 'sfir·ə·kəl di'grē }

spherical distance [MATH] The length of a great circle arc between two points on a sphere. { 'sfir·i·kəl 'dis·təns }

spherical-earth attenuation [ELECTROMAG] Attenuation over an imperfectly conducting spherical earth in excess of that over a perfectly conducting plane. { 'sfir·ə·kəl ¦ərth əˌten·yə'wā·shən }

spherical-earth factor [ELECTROMAG] The ratio of the electric field strength that would result from propagation over an imperfectly conducting spherical earth to that which would result from propagation over a perfectly conducting plane. { 'sfir·ə·kəl ¦ərth ˌfak·tər }

spherical excess [MATH] The sum of the angles of a spherical triangle, minus 180°. { 'sfir·ə·kəl ek'ses }

spherical geometry [MATH] The geometry of points on a sphere. { 'sfir·ə·kəl je'äm·ə·trē }

spherical harmonics [MATH] Solutions of Laplace's equation in spherical coordinates. { 'sfir·ə·kəl här'män·iks }

spherical indicatrix of binormal to a curve [MATH] All the end points of those radii from the sphere of radius one which are parallel to the positive direction of the binormal to a space curve. { 'sfir·ə·kəl ¦in·də¦kā·triks əv bī'nȯr·məl tü ə 'kərv }

spherical indicatrix of tangent to a curve [MATH] Those points on the unit sphere traced out by a radius moving from point to point always parallel with the tangent to the curve. ~~{ 'sfir·ə·kəl ¦in·də¦kā·triks əv 'tan·jən tü ə 'kərv }~~

spherical lens [OPTICS] A lens whose surfaces form portions of spheres. { 'sfir·ə·kəl 'lenz }

spherical mirror [OPTICS] A mirror, either convex or concave, whose surface forms part of a sphere. { 'sfir·ə·kəl 'mir·ər }

spherical pendulum [MECH] A simple pendulum mounted on a pivot so that its motion is not confined to a plane; the bob moves over a spherical surface. { 'sfir·ə·kəl 'pen·jə·ləm }

spherical polar coordinates *See* spherical coordinates. { 'sfir·ə·kəl 'pō·lər kō'ȯrd·ən·əts }

spherical polygon [MATH] A part of a sphere that is bounded by arcs of great circles. { 'sfir·ə·kəl 'päl·əˌgän }

spherical powder [MATER] A powder consisting of globular-shaped particles. { 'sfir·ə·kəl 'pau̇d·ər }

spherical pyramid [MATH] A solid bounded by a spherical polygon and portions of planes passing through the sides of the polygon and the center of the sphere. { 'sfir·ə·kəl 'pir·əˌmid }

spherical radius [MATH] For a circle on a sphere, the smaller of the spherical distances from one of the two poles of the circle to any point on the circle. { 'sfir·ə·kəl 'rād·ē·əs }

spherical sailing [NAV] Any of the sailing computation methods which are used to solve the problems of course, distance, difference of latitude, difference of longitude, and departure which take into account the spherical or spheroidal shape of the earth. { 'sfir·ə·kəl 'sāl·iŋ }

spherical sector [MATH] The cap and cone formed by the intersection of a plane with a sphere, the cone extending from the plane to the center of the sphere and the cap extending from the plane to the surface of the sphere. { 'sfir·ə·kəl 'sek·tər }

spherical segment [MATH] A solid that is bounded by a sphere and two parallel planes which intersect the sphere or are tangent to it. { 'sfir·ə·kəl 'seg·mənt }

spherical separator [PETRO ENG] A gas-oil separator in the form of a spherical vessel. { 'sfir·ə·kəl 'sep·əˌrād·ər }

spherical stress [MECH] The portion of the total stress that corresponds to an isotropic hydrostatic pressure; its stress tensor is the unit tensor multiplied by one-third the trace of the total stress tensor. { 'sfir·ə·kəl 'stres }

spherical surface [MATH] A surface whose total curvature has a constant positive value but that is not necessarily a sphere. { 'sfir·ə·kəl 'sər·fəs }

spherical surface harmonics [MATH] Functions of the two angular coordinates of a spherical coordinate system which are solutions of the partial differential equation obtained by separation of variables of Laplace's equation in spherical coordinates. Also known as surface harmonics. { ¦sfir·ə·kəl ¦sər·fəs här'män·iks }

spherical triangle [MATH] A three-sided surface on a sphere the sides of which are arcs of great circles. { 'sfir·ə·kəl 'trīˌaŋ·gəl }

spherical trigonometry [MATH] The study of spherical triangles from the viewpoint of angle, length, and area. { 'sfir·ə·kəl ˌtrig·ə'näm·ə·trē }

spherical wave [PHYS] A wave whose equiphase surfaces form a family of concentric spheres; the direction of travel is always perpendicular to the surfaces of the spheres. { 'sfir·ə·kəl 'wāv }

spherical weathering *See* spheroidal weathering. { 'sfir·ə·kəl 'weth·ə·riŋ }

spherical wedge [MATH] The portion of a sphere bounded by two semicircles and a lune (the surface of the sphere between the semicircles). { 'sfir·ə·kəl 'wej }

APPENDIX H

McGraw-Hill Dictionary of Scientific and Technical Terms, page 138 *(5th ed. 1994)*

ture of 88–92% crushed stone with the balance asphalt cement. { 'a,sfȯlt ,bläk }

asphalt cement [MATER] Fluxed or unfluxed asphalt especially prepared for direct use in making bituminous pavements. { 'a,sfȯlt si'ment }

asphalt cutter [MECH ENG] A powered machine having a rotating abrasive blade; used to saw through bituminous surfacing material. { 'a,sfȯlt ,kəd·ər }

asphalt emulsion [MATER] Asphalt cement in water containing a small amount of emulsifying agent. { 'a,sfȯlt i'məl·shən }

asphalt-emulsion slurry seal [MATER] A mixture of slow-setting emulsified asphalt, fine aggregate, and mineral filler, with water added to produce a slurry consistency. { 'a,sfȯlt i'məl·shən 'slə·rē ,sēl }

asphalt enamel [MATER] A surface coating composed of a mixture of asphalt, finely pulverized mica, clay, soapstone, or talc; applied to pipe that will be buried. { 'a,sfȯlt i'nam·əl }

asphaltene [MATER] Any of the dark, solid constituents of crude oils and other bitumens which are soluble in carbon disulfide but insoluble in paraffin naphthas; they hold most of the organic constituents of bitumens. { a'sfȯl,tēn }

asphalt flux [MATER] An oil used to reduce the consistency or viscosity of hard asphalt to the point required for use. { 'a,sfȯlt ,fləks }

asphalt fog seal [MATER] An asphalt surface treatment consisting of a light application of liquid asphalt without a mineral aggregate cover. { 'a,sfȯlt 'fäg ,sēl }

asphalt heater [ENG] A piece of equipment for raising the temperature of bitumen used in paving. { 'a,sfȯlt 'hēd·ər }

asphaltic base oil [MATER] A crude oil that has asphaltum as the predominating solid residual. { a'sfȯlt·ik ¦bas ,ȯil }

asphaltic concrete [MATER] A special concrete consisting of a mixture of graded aggregate and heated asphalt; must be applied and spread while hot. { a'sfȯlt·ik 'kän,krēt }

asphaltic material [MATER] A solid, liquid, or semisolid mixture of heavy hydrocarbons and nonmetallic derivatives; obtained from naturally occurring bituminous deposits or from residues of petroleum refining. { a'sfȯl·tik mə'tir·ē·əl }

asphaltic road oil [MATER] A thick, fluid solution of asphalt. { a'sfȯlt·ik 'rōd ,ȯil }

asphaltic sand [GEOL] Deposits of sand grains cemented together with soft, natural asphalt. { a'sfȯlt·ik 'sand }

asphaltite [GEOL] Any of the dark-colored, solid, naturally occurring bitumens that are insoluble in water, but more or less completely soluble in carbon disulfide, benzol, and so on, with melting points between 250 and 600°F (121–316°C); examples are gilsonite and grahamite. { a'sfȯl,tīt }

asphaltite coal *See* albertite. { a'sfȯl,tīt ,kōl }

asphalt lamination [MATER] A laminate of sheet material, such as paper or felt, which uses asphalt as the adhesive. { 'a,sfȯlt ,lam·ə'nā·shən }

asphalt leveling course [CIV ENG] A layer of an asphalt-aggregate mixture of variable thickness, used to eliminate irregularities in contour of an existing surface, prior to the placement of a superimposed layer. { 'a,sfȯlt 'lev·əl·iŋ ,kȯrs }

asphalt macadam [MATER] Pavement made with an asphalt binder rather than tar. { 'a,sfȯlt mə'kad·əm }

asphalt mastic [MATER] A mixture of asphalt with sand, asbestos, crushed rock, or similar material; used like cement. Also known as mastic asphalt. { 'a,sfȯlt 'mas·tik }

asphalt overlay [CIV ENG] One or more layers of asphalt construction on an existing pavement. { 'a,sfȯlt 'ōv·ər,lā }

asphalt paint [MATER] Asphaltic material dissolved in volatile solvent with or without pigments, drying oils, resins, and so on. { 'a,sfȯlt 'pānt }

asphalt paper [MATER] A paper that is coated or impregnated with asphalt. { 'a,sfȯlt 'pā·pər }

asphalt pavement [CIV ENG] A pavement consisting of a surface layer of mineral aggregate, coated and cemented together with asphalt cement on supporting layers. { 'a,sfȯlt 'pāv·mənt }

asphalt primer [MATER] Low-viscosity, liquid asphaltic material applied to and absorbed by nonbituminous surfaces, as in waterproofing. { 'a,sfȯlt 'prīm·ər }

asphalt rock [GEOL] Natural asphalt-containing sandstone or dolomite. Also known as asphalt stone; bituminous rock; rock asphalt. { 'a,sfȯlt 'räk }

asphalt roofing [MATER] A roofing material made by impregnating a dry roofing felt with a hot asphalt saturant, applying asphalt coatings to the weather and reverse sides, and embedding a mineral surfacing in the coating on the weather side. { 'a,sfȯlt 'rüf·iŋ }

asphalt shingle [MATER] A roof shingle made of felt impregnated with asphalt and covered with mineral granules. { 'a,sfȯlt 'shiŋ·gəl }

asphalt soil stabilization [CIV ENG] The treatment of naturally occurring nonplastic or moderately plastic soil with liquid asphalt at normal temperatures to improve the load-bearing qualities of the soil. { 'a,sfȯlt ¦sȯil ,stāb·ə·lə'zā·shən }

asphalt stone *See* asphalt rock. { 'a,sfȯlt 'stōn }

asphalt tile [MATER] Floor tile composed of asbestos fibers, mineral coloring pigments, and inert fillers bound together; used on rigid subfloors or hardwood floors. { 'a,sfȯlt 'tīl }

asphaltum [MATER] Bituminous material in oil of turpentine; used in photomechanical work because of its ability to be rendered insoluble in light. { a'sfȯl·təm }

aspheric surface [OPTICS] A lens or mirror surface which is altered slightly from a spherical surface in order to reduce aberrations. { ā'sfir·ik 'sər·fəs }

asphradium [INV ZOO] An organ, believed to be a chemoreceptor, in mollusks. Also spelled osphradium. { a'sfrād·ē·əm }

asphyxia [MED] Suffocation due to oxygen deprivation, resulting in anoxia and carbon dioxide accumulation in the body. { a'sfik·sē·ə }

aspiculate [INV ZOO] Lacking spicules, referring to Porifera. { a'spik·yə·lət }

Aspidiotinae [INV ZOO] A subfamily of homopteran insects in the superfamily Coccoidea. { a,spid·ē'ä·tə,nē }

Aspidiphoridae [INV ZOO] An equivalent name for the Sphindidae. { a,spid·ə'fȯr·ə,dē }

Aspidobothria [INV ZOO] An equivalent name for the Aspidogastrea. { ¦as·pə,dō'bäth·rē·ə }

Aspidobothroidea [INV ZOO] A group of trematodes accorded class rank by W. J. Hargis. { ¦as·pə,dō·bə'thrȯid·ē·ə }

Aspidobranchia [INV ZOO] An equivalent name for the Archaeogastropoda. { ¦as·pə,dō'braŋk·ē·ə }

Aspidochirotacea [INV ZOO] A subclass of bilaterally symmetrical echinoderms in the class Holothuroidea characterized by tube feet and 10–30 shield-shaped tentacles. { ¦as·pə,dō,kī·rə'tās·ē·ə }

Aspidochirotida [INV ZOO] An order of holothurioid echinoderms in the subclass Aspidochirotacea characterized by respiratory trees and dorsal tube feet converted into tactile warts. { ¦as·pə,dō,kī'räd·ə·də }

Aspidocotylea [INV ZOO] An equivalent name for the Aspidogastrea. { ¦as·pə,dō,käd·ə'lē·ə }

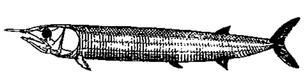
Aspidodiadematidae [INV ZOO] A small family of deep-sea echinoderms in the order Diadematoida. { ¦as·pə,dō,dī·ə·də'mad·ə,dē }

Aspidogastrea [INV ZOO] An order of endoparasitic worms in the class Trematoda having strongly developed ventral holdfasts. { ¦as·pə,dō'gas·trē·ə }

Aspidogastridae [INV ZOO] A family of trematode worms in the order Aspidogastrea occurring as endoparasites of mollusks. { ¦as·pə,dō'gas·trə,de }

Aspidorhynchidae [PALEON] The single family of the Aspidorhynchiformes, an extinct order of holostean fishes. { ¦as·pə,dō'riŋ·kə,dē }

ASPIDORHYNCHIFORMES



Aspidorhynchus acutirostris (Blainville), Upper Jurassic, Bavaria, length to 3 feet (91 centimeters).

Aspidorhynchiformes [PALEON] A small, extinct order of specialized holostean fishes. { ¦as·pə,dō,riŋk·ə'fȯr,mēz }

aspidospermine [PHARM] $C_{22}H_{30}O_2N_2$ White to brownish-yellow crystals with a melting point of 132–136°C; soluble in water, alcohol, chloroform, and ether; used in medicine. { ¦as·pə,dō'spər,mēn }

Aspinothoracida [PALEON] The equivalent name for Brachythoraci. { a,spīn·ō·thə'ras·əd·ə }

aspirating *See* dedusting. { 'as·pə,rād·iŋ }

aspirating burner [ENG] A burner in which combustion air at high velocity is drawn over an orifice, creating a negative static pressure and thereby sucking fuel into the stream of air; the mixture of air and fuel is conducted into a combustion chamber, where the fuel is burned in suspension. { 'as·pə,rād·iŋ 'bər·nər }

aspirating screen [MIN ENG] A vibrating screen from which light, liberated particles are removed by suction. { 'as·pə,rād·iŋ 'skrēn }

APPENDIX I

Affidavit under 35 U.S.C. 1.132 by Games K Guenter

FILED VIA E-FILE

PATENT APPLICATION
Docket No. 15436.441.3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of		)
	Bo Su Chen et al.	)
Serial No.:	10/612,660	) Art Unit
		) 2874
Filed:	July 2, 2003	)
For:	A LENS OPTICAL COUPLER	)
Confirmation No.:	5518	)
Customer No.:	022913	)
Examiner:	Michelle R. Connelly Cushwa	)

DECLARATION UNDER SECTION 1.132

The undersigned, hereby declare as follows:

1. I, James K Guenter, work for Advanced Optical Components, a division of Finisar Corporation, the assignee of the above-identified application.

2. I have a degree in physics and 28 years of experience working in the field of optics and optical component design.

3. I am one of the named inventors in U.S. Patent Application Publication 2004//0247242 to Blasingame et al. (hereinafter "*Blasingame*"). I hereby certify that lens 26 in *Blasingame* is clearly not an aspherical lens. Lens 26 is explicitly a half-ball lens, and any lens whose surface is any fraction of a sphere is a spherical lens. One having taken an introductory course in optics or lens design would not consider a half-ball lens an aspherical lens.

4. The technical distinction between a spherical lens on the one hand, and an aspherical lens on the other hand, is one that is well known and accepted in the field of optics and optical component design and is a view that is well developed in the literature. For example, excerpts from the following technical texts make it quite clear that any surface that is a portion of a sphere, including a plano surface, cannot be an asphere:

a. The first sentences in section A of *Lens Design Fundamentals,* by Rudolf Kingslake (Academic Press, 1978) (attached hereto as Exhibit A) teaches that a plano surface is a spherical surface with infinite radius, and the second paragraph teaches that an aspheric surface by definition has an axis of symmetry that must be made to coincide with the optical axis of any design, whereas spherical surfaces, for which any radius is equivalent, have no such axis.

b. Also, pages 215-216 of *Elements of Modern Optical Design*, by Donald O'Shea (John Wiley and Sons, 1985) (attached hereto as Exhibit B) further demonstrates the technical distinction between an aspherical lens and a spherical lens, such as a half-ball lens. In particular, the cited portions teach that an asphere is usually defined by its departure from some reference sphere. This is expressed as the difference between the sphere and the asphere at different heights above the optic axis, as shown in Fig. 6.23. Since the curvature of a half ball lens does not depart from some reference sphere it cannot be considered an asphere.

5. As disclosed on page 6 lines 13-22 of this application (SN 10/612,660) the combination of the glass spherical lens and the plastic aspherical lens has a synergistic effect

where an aspherical plastic lens compensates for the ball lens' spherical aberration and the glass ball lens compensates for poor thermal properties of the plastic aspherical lens. This same synergistic effect would not be realized by a ball lens and half-ball lens configuration.

> The aberration of the ball lens may degrade the efficiency of the coupling system. However, the ball lens' spherical aberration may be compensated by the light ray directing properties of the aspherical plastic lens. Since the ball lens may have significantly more optical power than the plastic lens in the coupling system, the plastic lens' poor thermal properties may be compensated for and minimized. Therefore, an appropriately designed combination of a glass ball lens and plastic molded aspherical lens may provide a thermally stable and highly efficient optical coupling system.

Page 6 lines 13-22 U.S. Patent Application 10/612,660.

6. I hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable for fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

DATED this 25th day of June, 2007.

Respectfully submitted,

JAMES K GUENTER

APPENDIX A

Elements of Modern Optical Design, Donald O'Shea, page 216 *(1985)*

single piece of glass having polished surfaces, and a complete lens thus contains one or more elements. Sometimes a group of elements, cemented or closely airspaced, is referred to as a "component" of a lens. However, these usages are not standardized and the reader must judge what is meant when these terms appear in a book or article.

I. RELATIONS BETWEEN DESIGNER AND FACTORY

The lens designer must establish good relations with the factory because, after all, the lenses that he designs must eventually be made. He should be familiar with the various manufacturing processes and work closely with the optical engineers. He must always bear in mind that lens elements cost money, and he should therefore use as few of them as possible if cost is a serious factor. Sometimes, of course, image quality is the most important consideration, in which case no limit is placed on the complexity or size of a lens. Far more often the designer is urged to economize by using fewer elements, flatter lens surfaces so that more lenses can be polished on a single block, lower-priced types of glass, and thicker lens elements since they are easier to hold by the rim in the various manufacturing operations.

A. Spherical versus Aspheric Surfaces

In almost all cases the designer is restricted to the use of spherical refracting or reflecting surfaces, regarding the plane as a sphere of infinite radius. The standard lens manufacturing processes[1] generate a spherical surface with great accuracy, but attempts to broaden the designer's freedom by permitting the use of nonspherical or "aspheric" surfaces lead to extremely difficult manufacturing problems; consequently such surfaces are used only when no other solution can be found. The aspheric plate in the Schmidt camera is a classic example. However, molded aspheric surfaces are very practical and can be used wherever the production rate is sufficiently high to justify the cost of the mold; this applies particularly to plastic lenses made by injection molding. Fairly accurate parabolic surfaces can be generated on glass by special machines.

In addition to the problem of generating and polishing a precise aspheric surface, there is the further matter of centering. Centered lenses with spherical surfaces have an optical axis that contains the centers of curvature of all the surfaces, but an aspheric surface has its own independent axis, which must be made to coincide with the axis containing all the other centers of

[1] F. Twyman, "Prism and Lens Making," Hilger and Watts, London, 1952. D. F. Horne, "Optical Production Technology," Crane Russak, New York, 1972.

curvature in the system. Most astronomical instruments and a few photographic lenses and eyepieces have been made with aspheric surfaces, but the designer is advised to avoid such surfaces if at all possible.

B. Establishment of Thicknesses

Negative lens elements should have a center thickness between 6 and 10% of the lens diameter, but the establishment of the thickness of a positive element requires much more consideration. The glass blank from which the lens is made must have an edge thickness of at least 1 mm to enable it to be held during the grinding and polishing operations (Fig. 1). At least 1 mm

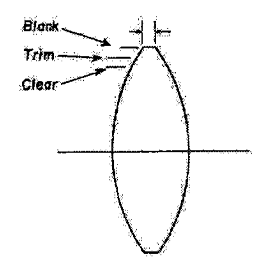


Fig. 1. Assigning thickness to a positive element.

will be removed in edging the lens to its trim diameter, and we must allow at least another 1 mm in radius for support in the mount. With these allowances in mind, and knowing the surface curvatures, the minimum acceptable center thickness of a positive lens can be determined. These specific limitations refer to a lens of average size, say $\frac{1}{2}$ to 3 in. in diameter; they may be somewhat reduced for small lenses, and they must be increased for large ones. A knife-edge lens is very hard to make and handle and it should be avoided wherever possible. A discussion of these matters with the glass-shop foreman can be very profitable.

As a general rule, weak lens surfaces are cheaper to make than strong surfaces because more lenses can be polished together on a block. However, if only a single lens is to be made, multiple blocks will not be used, and then a strong surface is no more expensive than a weak one.

A small point but one worth noting is that a lens that is nearly equiconvex is liable to be accidentally cemented or mounted back-to-front in assembly. If possible such a lens should be made exactly equiconvex by a trifling bending, any aberrations so introduced being taken up elsewhere in the system. Another point to notice is that a very small edge separation between two lenses is hard to achieve, and it is better either to let the lenses

APPENDIX B

Lens Design Fundamentals, Rudolf Kingslake, pages 2 and 3 (1978)

difference between the sphere and the asphere at different heights above the optic axis, as shown in Fig. 6.23. First the distance between the plane at the sphere vertex and the sphere is determined. This is referred to as the sagitta or "sag" of the surface at different distances from the optic axis. For a sphere the sag may be written as

$$z_s = \frac{c\rho^2}{1 + \sqrt{1 - c^2\rho^2}}, \tag{6.50}$$

where $c = 1/R$, the curvature of the surface, and $\rho = \sqrt{x^2 + y^2}$, the distance from the optic axis. If c^2 in the denominator of Eq. 6.50 is replaced by $(1 + \kappa)c^2$, the equation gives the sag for an asphere, which is a conic section of revolution, κ is the conic constant ($\kappa = 0$ for a sphere, $\kappa = -1$ for a parabola, $-1 < \kappa < 0$ for ellipsoid, and $\kappa < -1$ for a hyperbola). Depending on the conjugate distances and the presence of other elements in the system, different conic sections are used to construct systems with no spherical aberration. Additional corrections for off-axis aberrations can be made by introducing surfaces that can be represented as higher order polynomials of $c^2\rho^2$ (i.e., $(x^2 + y^2)/R^2$). The added degrees of freedom provided by allowing surfaces to be aspheric must be balanced against the difficulty and increased cost of producing such surfaces.

An example of an aspheric surface in an optical system is the Schmidt corrector plate used for systems with large light-gathering power, such as TV projection systems, missile tracking cameras, and wide-field telescopes. The plate has a fourth-power curve of the form $z_\alpha = \alpha\rho^2 + \beta\rho^4$.

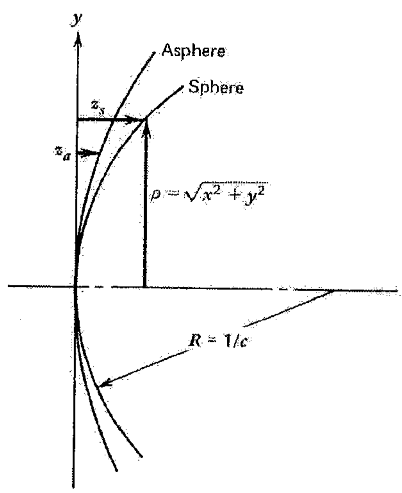


Figure 6.23. Aspheric surface. Definition of an asphere as a departure from a spherical surface.